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Article

Colonoscopy Research Collaboration: A Comprehensive Network Analysis of the Structure and Impact of Research Partnerships

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Abstract: **Aim:** This study aims to analyze the structure and impact of research collaborations in colonoscopy from 2000 to 2023 by examining co-authorship networks. The goal is to understand the evolution of these networks, identify key contributors, and assess how collaborative relationships influence the field. **Method:** I conducted a comprehensive network analysis of co-authorship patterns using data from the Web of Science (WoS) Core Collection database. The analysis included 41,213 articles related to colonoscopy published between 2000 and 2023. Using Python (Version 3.10.5) and PyCharm (Software Version 2022.1.3), we evaluated the networks through macro-level indicators (network density, clustering coefficient, number of components, average distance) and micro-level indicators (degree centrality, closeness centrality, betweenness centrality). **Result:** The analysis revealed a network with increasing but still fragmented collaboration over the years. The network density showed low proportions of realized connections relative to potential ones, with a high clustering coefficient indicating tight-knit groups when collaborations occurred. The number of components remained high, reflecting a fragmented structure. Prominent researchers such as Hassan, Cesare (Italy) and Dekker, Evelien (Netherlands) consistently emerged as central figures across different periods, demonstrating significant roles in facilitating connections between various research clusters. **Conclusion:** The study highlights a growing but fragmented collaborative landscape in colonoscopy research. Key researchers have played central roles in connecting different parts of the network, yet there remains substantial room for further integration. Strengthening collaborations across isolated groups could enhance the cohesiveness and impact of research in this field.

Keywords: gastroenterology; colonoscopy; co-authorship network analysis; network analysis; research collaboration; research trend analysis; research trends; key researchers; research strategies; internal medicine; planning future collaborative studies

Introduction

Background and Objectives

Colonoscopy is a critical procedure in the detection, diagnosis, and management of colorectal diseases, including colorectal cancer, which remains a significant global health concern. As one of the most common cancers worldwide, colorectal cancer accounts for a substantial burden in terms of morbidity and mortality, particularly in developed countries. The advancement of colonoscopy technology and techniques has greatly contributed to the early detection and prevention of colorectal cancer, highlighting the importance of research in this field. However, despite these advancements, several challenges persist, including variability in screening uptake, access to advanced procedures, and disparities in outcomes across different regions.

Globally, the research landscape in colonoscopy is highly dynamic, with significant contributions from regions such as North America and Europe. In these regions, extensive research efforts have led to innovations in techniques and technologies, and the establishment of robust

clinical guidelines. In Europe and the United States, the emphasis has been on enhancing the quality of colonoscopy through training, standardization of procedures, and integration of artificial intelligence to improve diagnostic accuracy. Meanwhile, in Asia, there is a notable increase in research activity driven by a growing emphasis on preventive health and the rising incidence of colorectal diseases. Countries like Japan and China contribute significantly to the global body of knowledge with advancements in endoscopic techniques and research into genetic and environmental factors influencing colorectal health.

The purpose of this study is to analyze the collaborative structures within colonoscopy research by examining co-authorship networks from 2000 to 2023 using data from the Web of Science (WoS) Core Collection database. Understanding these networks provides insights into the cooperative relationships between researchers, the evolution of research groups, and the overall impact of these collaborations on the field. Network analysis offers a powerful framework for uncovering the underlying structure of scientific collaboration and identifying key players and influential research clusters that drive the field forward.

Scope of the Study

This study examines publications related to colonoscopy research indexed in the WoS Core Collection database between 2000 and 2023. A total of 41,213 articles were selected for analysis, providing a comprehensive overview of the collaborative landscape within this specialized field over the past two decades. The dataset ensures the inclusion of the most recent publications (as of September 2024). The analysis will focus on constructing and evaluating co-authorship networks using macro-level indicators such as network density (the ratio of actual to possible connections), clustering coefficient (the degree to which nodes tend to cluster together), number of components (distinct connected subgroups within the network), and average path length (the average distance between nodes). At the micro-level, I will assess degree centrality (the number of direct connections each node has), closeness centrality (how close a node is to all other nodes), and betweenness centrality (the extent to which a node lies on the shortest path between other nodes). These metrics will help illuminate the structure and dynamics of researcher collaborations in this field.

Significance of the Study

The findings of this study hold significant implications for the field of colonoscopy research. By identifying key researchers and institutions, this analysis can highlight leading contributors and potential areas for strengthening collaborations. Understanding the evolution of international collaborative networks is essential for fostering global research partnerships, which are increasingly important in addressing the complex challenges in colorectal disease prevention and treatment. This study also aims to assess the impact of these collaborations on scientific output and innovation within the field.

Moreover, the analysis of network structures and their changes over time can provide valuable insights into the dynamics of colonoscopy research, revealing how collaborations have shifted and evolved in response to emerging trends and challenges. This understanding is crucial for guiding future research directions and enhancing the effectiveness of collaborative efforts. Additionally, by highlighting the importance of international cooperation, this study underscores the value of continued global engagement to advance the field of colonoscopy and improve patient outcomes worldwide.

Material and Methods

The present study investigates the co-authorship patterns in colonoscopy research papers. I utilized the WoS Core Collection database, conducting a "Topic Search" with the keyword "colonoscopy" to analyze a total of 41,213 articles published between 2000 and 2023 (as of September 2024). In this analysis, I examined who collaborated with whom in co-authoring these papers. I conducted network analysis using the Python programming language (version 3.10.5) within the

integrated development environment (IDE) PyCharm (software version 2022.1.3). This study employed methodology-established principles of social network analysis [5]. I carried out the analysis in two main parts:

Macro-Level Metrics:

Network Density: Calculated as the ratio of the number of edges to the maximum possible edges Between all nodes.

Clustering Coefficient: Measured the extent to which nodes form clusters by considering the number of edges among neighboring nodes and calculating the average.

Components: Identified and counted the number of subgraphs (components) where nodes are mutually connected.

Average Path Length: Evaluated the average “distance” between nodes by calculating the overall average path length in the network [6].

Micro-Level Metrics:

Degree Centrality: Measured the importance of each node by counting the number of edges it has in the network.

Closeness Centrality: Defined as the inverse of the sum of the shortest path lengths from a node to all other nodes, measuring how close each node is to others in the network.

Betweenness Centrality: Assessed the extent to which a node lies on the shortest paths between other nodes, indicating its importance in information transmission within the network [6,7].

The significance of these macro-level metrics in understanding the structure of scientific collaboration networks and these micro-level centrality measures in scientific collaboration networks has been well documented and used [6,7]. Through these analyses, I can identify collaborative relationships and influential researchers in colonoscopy research. This information may be useful for understanding research trends and planning future collaborative studies.

Results

The study analyzed the co-authorship network of researchers in colonoscopy research, focusing on the periods from 2000 to 2023. The analysis was conducted using data from the WoS Core Collection and utilized both macro and micro-level network metrics to understand the evolution of collaborative networks in this field.

2000-2009. Network Analysis

During the 2000-2009 period, the co-authorship network of colonoscopy research was characterized by a very sparse structure (Figure 1). The network density was 0.000258 (Table 1), indicating that only a small fraction of potential connections between authors were realized (Figure 1). The average clustering coefficient was relatively high at 0.890 (Table 1), suggesting that when collaborations occurred, they were likely to form tight-knit groups (Figure 1). However, the network consisted of 2,643 components (Table 1), demonstrating a highly fragmented structure with many isolated groups of authors and no single large connected component (Figure 1). The average distance between nodes was infinite, reflecting the overall disconnected nature of the network during this period [8].

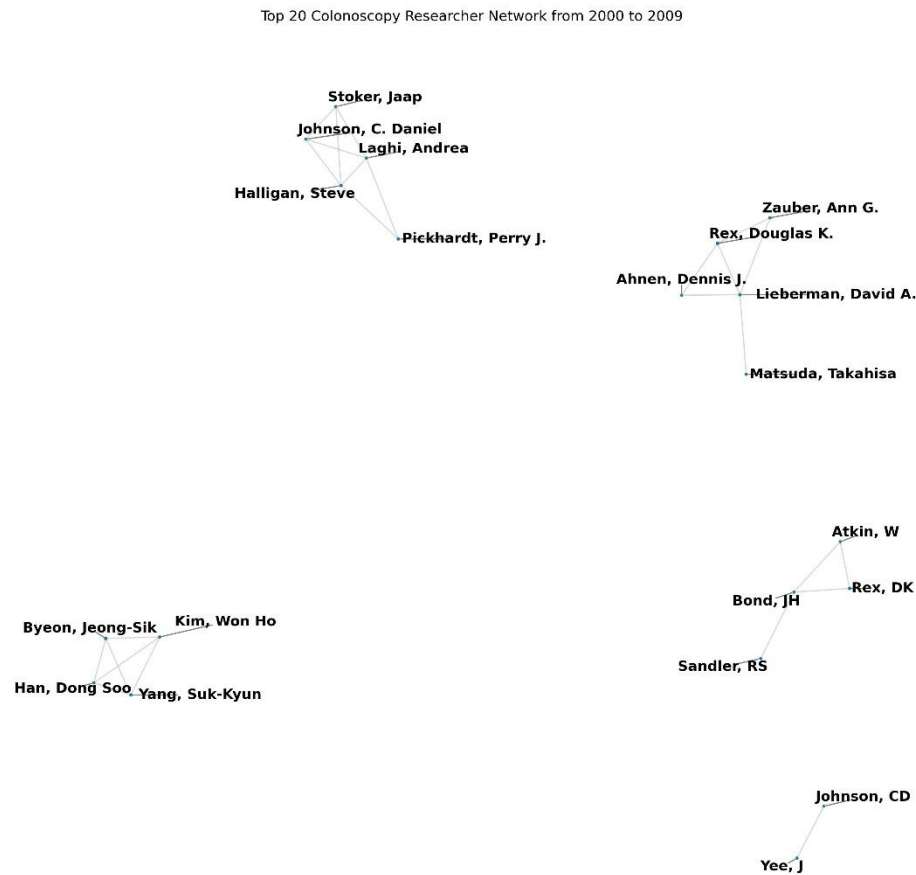


Figure 1. Top 20 Colonoscopy Researcher Network from 2000 to 2009.

Table 1. Network Metrics.

Metric	2000 - 2009	2010 - 2019	2020 - 2023
Network Density	0.000258	0.000171	0.000265
Average Clustering Coefficient	0.890	0.882	0.904
Number of Components	2643	3865	3022
Average Distance	infinite	infinite	infinite

At the micro-level, degree centrality analysis revealed that Byeon, Jeong-Sik, Rex, Douglas K., and Lieberman, David A. were among the top contributors, indicating their high collaboration frequency within the network (Table 2). Notably, Byeon, Jeong-Sik had the highest degree centrality at 0.0044, followed closely by Rex, Douglas K. with 0.0042 (Table 2). Closeness centrality highlighted Atkin, W., and Rex, DK as central figures, with Atkin, W. having the highest closeness centrality score

of 0.0578, which indicates that these authors were well-positioned to efficiently interact with other nodes in the network (Table 3). Betweenness centrality identified Atkin, W. and Jass, Jeremy R. as pivotal nodes, with Atkin, W. having the highest score of 0.0099, underscoring their roles as key intermediaries in connecting different parts of the network (Table 4).

Table 2. Top 20 Nodes by Degree Centrality.

No de	2000 - 2009	Degree Centrality	2010 - 2019	Degree Centrality	2020 - 2023	Degree Centrality
1	Byeon, Jeong-Sik	0.0044	Hassan, Cesare	0.0094	Hassan, Cesare	0.0133
2	Rex, Douglas K.	0.0042	Dekker, Evelien	0.0092	Dekker, Evelien	0.0128
3	Lieberman, David A.	0.0038	Pellise, Maria	0.0070	Repici, Alessandro	0.0102
4	Rex, DK	0.0037	Rex, Douglas K.	0.0067	Sharma, Prateek	0.0091
5	Yang, Suk- Kyun	0.0034	Kuipers, Ernst J.	0.0060	Saito, Yutaka	0.0090
6	Zauber, Ann G.	0.0033	Repici, Alessandro	0.0051	Pellise, Maria	0.0089
7	Pickhardt, Perry J.	0.0033	Senore, Carlo	0.0051	Lansdorp- Vogelaar, Iris	0.0085
8	Halligan, Steve	0.0033	Saito, Yutaka	0.0050	Moreira, Leticia	0.0082
9	Matsuda, Takahisa	0.0032	Lansdorp- Vogelaar, Iris	0.0049	Balaguer, Francesc	0.0078
10	Stoker, Jaap	0.0032	Matsuda, Takahisa	0.0047	Brenner, Hermann	0.0078
11	Johnson, C. Daniel	0.0031	Siersema, Peter D.	0.0046	Hampel, Heather	0.0077
12	Yee, J	0.0030	Jover, Rodrigo	0.0046	Antonelli, Giulio	0.0064
13	Kim, Won Ho	0.0030	Castells, Antoni	0.0046	Hoffmeister, Michael	0.0063
14	Bond, JH	0.0029	Dekker, E.	0.0046	Lindblom, Annika	0.0063
15	Laghi, Andrea	0.0029	Quintero, Enrique	0.0045	Newcomb, Polly A.	0.0063
16	Han, Dong Soo	0.0029	Bujanda, Luis	0.0043	Jenkins, Mark A.	0.0063
17	Sandler, RS	0.0028	Zauber, Ann G.	0.0042	Buchanan, Daniel D.	0.0061
18	Atkin, W	0.0026	Fockens, Paul	0.0040	Win, Aung Ko	0.0061

19	Ahnen, Dennis J.	0.0026	Pickhardt, Perry J.	0.0039	Hopper, John L.	0.0061
20	Johnson, CD	0.0026	Ahnen, Dennis J.	0.0039	Thibodeau, Stephen N.	0.0061

Table 3. Top 20 Nodes by Closeness Centrality.

Node	2000 - 2009	Closeness Centrality	2010 - 2019	Closeness Centrality	2020 - 2023	Closeness Centrality
1	Atkin, W	0.0578	Hassan, Cesare	0.1885	Hassan, Cesare	0.1854
2	Rex, DK	0.0573	Rex, Douglas K.	0.1854	Dekker, Evelien	0.1845
3	Provenzale, D	0.0569	Dekker, Evelien	0.1849	Repici, Alessandro	0.1829
4	Bond, JH	0.0557	Pellise, Maria	0.1818	Sharma, Prateek	0.1823
5	Lieberman, DA	0.0553	Matsuda, Takahisa	0.1812	Saito, Yutaka	0.1802
6	Winawer, S	0.0552	Kaminski, Michal F.	0.1811	East, James E.	0.1791
7	Rex, D	0.0541	Radaelli, Franco	0.1804	Rex, Douglas K.	0.1787
8	Lieberman, David A.	0.0539	Senore, Carlo	0.1787	Bhandari, Pradeep	0.1776
9	Farraye, FA	0.0536	Kaltenbach, Tonya	0.1772	Antonelli, Giulio	0.1760
10	Burt, RW	0.0534	Sharma, Prateek	0.1766	Bisschops, Raf	0.1757
11	Levin, TR	0.0534	East, James E.	0.1762	Bretthauer, Michael	0.1755
12	Johnson, DA	0.0530	Jover, Rodrigo	0.1756	Mori, Yuichi	0.1752
13	Kirk, LM	0.0530	Schoen, Robert E.	0.1747	Chiu, Han-Mo	0.1743
14	Lambert, R	0.0528	Bisschops, Raf	0.1746	Lieberman, David	0.1742
15	Hoff, G	0.0528	Rastogi, Amit	0.1746	Rutter, Matthew D.	0.1735
16	Watanabe, H	0.0527	Kuipers, Ernst J.	0.1742	Dinis-Ribeiro, Mario	0.1735
17	Schoen, RE	0.0526	Gupta, Neil	0.1741	Senore, Carlo	0.1731

18	McQuaid, KR	0.0524	Repici, Alessandro	0.1740	Sung, Joseph J. Y.	0.1729
19	O'Brien, Michael J.	0.0523	Spada, Cristiano	0.1737	Gupta, Samir	0.1726
20	Dixon, MF	0.0523	Robertson, Douglas J.	0.1734	Yu, Honggang	0.1724

Table 4. Top 20 Nodes by Betweenness Centrality.

Node	2000 - 2009	Betweenness Centrality	2010 - 2019	Betweenness Centrality	2020 - 2023	Betweenness Centrality
1	Atkin, W	0.0099	Dekker, E.	0.0547	Sharma, Prateek	0.0246
2	Jass, Jeremy R.	0.0094	Hassan, Cesare	0.0323	Saito, Yutaka	0.0243
3	Lieberman, David A.	0.0088	Matsuda, Takahisa	0.0316	Yu, Honggang	0.0224
4	Rex, DK	0.0074	Rex, Douglas K.	0.0304	Dekker, Evelien	0.0194
5	Togashi, Kazutomo	0.0071	Pellise, Maria	0.0196	Hassan, Cesare	0.0191
6	Thomson, Mike	0.0070	Dekker, Evelien	0.0186	Brenner, Hermann	0.0127
7	Yamamoto, H.	0.0069	Saito, Yutaka	0.0129	Byeon, Jeong-Sik	0.0121
8	Vieth, Michael	0.0068	Muthusamy, V. Raman	0.0123	Chiu, Han-Mo	0.0118
9	Kiesslich, Ralf	0.0064	Pickhardt, Perry J.	0.0122	Repici, Alessandro	0.0114
10	Watanabe, H	0.0058	Radaelli, Franco	0.0109	East, James E.	0.0113
11	Yee, Judy	0.0055	Wallace, Michael B.	0.0104	Pellise, Maria	0.0104
12	Provenzale, D	0.0052	Kuipers, Ernst J.	0.0101	Lieberman, David	0.0099
13	Zauber, Ann G.	0.0052	Schoen, Robert E.	0.0093	Shaukat, Aasma	0.0094
14	Fu, K. I.	0.0045	Jover, Rodrigo	0.0092	Senore, Carlo	0.0091
15	Sung, Joseph J.	0.0040	Hassan, C.	0.0090	Gupta, Samir	0.0090
16	Matsuda, Takahisa	0.0039	Kaltenbach, Tonya	0.0088	Rex, Douglas K.	0.0087

17	Van Gossum, Andre	0.0036	Sano, Yasushi	0.0086	Dekker, E.	0.0079
18	Bond, JH	0.0035	Tanaka, Shinji	0.0084	Sung, Joseph J. Y.	0.0079
19	Rex, Douglas K.	0.0035	Byeon, Jeong-Sik	0.0077	Chan, Andrew T.	0.0071
20	Cohen, J	0.0035	Senore, Carlo	0.0076	Schoen, Robert E.	0.0069

2010-2019. Network Analysis

In the 2010-2019 period, the network density decreased slightly to 0.000171 (Table 1), indicating that despite the increased number of collaborations, the potential connections between authors were still underutilized. The average clustering coefficient remained high at 0.882 (Table 1), suggesting persistent clustering tendencies among collaborating authors (Figure 2). The number of components increased to 3,865, reflecting the expanding but still highly fragmented collaboration landscape in colonoscopy research (Figure 2). Similar to the earlier period, the average distance remained infinite, pointing to the absence of a fully connected network structure [8].

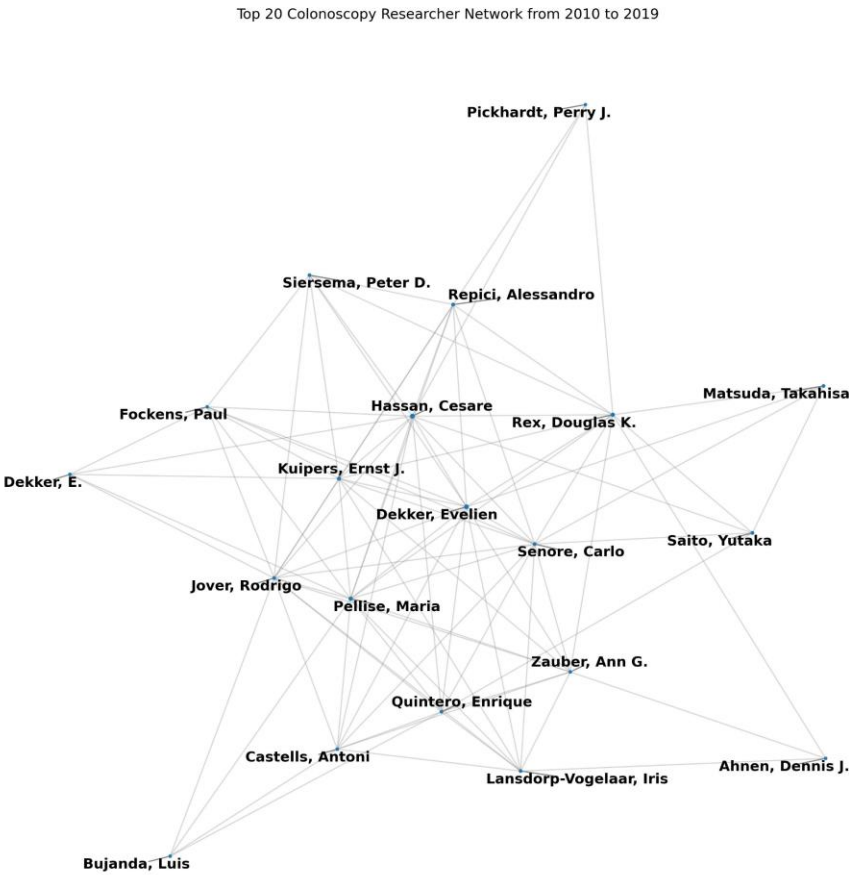


Figure 2. Top 20 Colonoscopy Researcher Network from 2010 to 2019.

On the micro-level, the analysis identified Hassan, Cesare as the most prominent author by degree centrality, with a score of 0.0094, making him the most frequently collaborating author in this period. Dekker, Evelien and Pellise, Maria also featured prominently, demonstrating their active participation in collaborative research efforts (Table 2). In terms of closeness centrality, Hassan, Cesare continued to lead with a score of 0.1885, reflecting his central role in the network’s structure. Rex, Douglas K., and Dekker, Evelien also maintained high closeness centrality scores, indicating their importance in maintaining efficient communication paths across the network (Table 3). Betweenness centrality highlighted Dekker, E. and Hassan, Cesare as crucial connectors within the network, with Dekker, E. having the highest betweenness score of 0.0547, signifying their significant influence in facilitating collaboration between otherwise distant groups of researchers (Table 4).

2020-2023. Network Analysis

During the 2020-2023 period, the co-authorship network for colonoscopy research showed a network density of 0.000265 (Table 1), which indicates that although the total number of collaborations increased, the proportion of realized connections among potential ones remained low. The average clustering coefficient was 0.904 (Table 1), reflecting a strong tendency for researchers to

form tightly interconnected groups (Figure 3). The network consisted of 3,022 components (Table 1), highlighting a still fragmented structure with numerous small, isolated clusters and no single dominant connected component (Figure 3). The average distance between nodes remained infinite, pointing to the ongoing lack of full connectivity across the network [8].

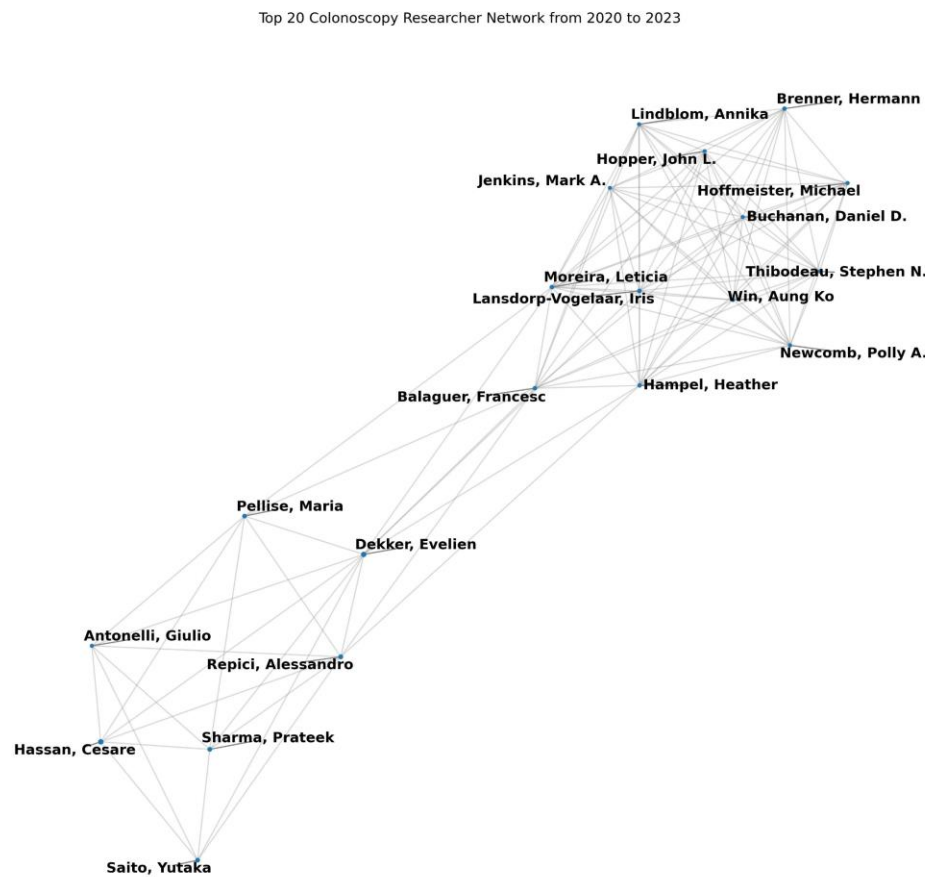


Figure 3. Top 20 Colonoscopy Researcher Network from 2020 to 2023.

At the micro-level, degree centrality analysis identified Hassan, Cesare as the most prominent author with the highest degree centrality score of 0.0133, indicating frequent collaborations. He was followed closely by Dekker, Evelien (0.0128) and Repici, Alessandro (0.0102), demonstrating their active roles in the network. Closeness centrality showed Hassan, Cesare continuing to occupy a central position with a closeness score of 0.1854, followed by Dekker, Evelien (0.1845) and Repici, Alessandro (0.1829), suggesting these researchers were well-placed for efficient interaction with others. Betweenness centrality further highlighted Sharma, Prateek (0.0246) and Saito, Yutaka (0.0243) as critical intermediaries within the network, with Hassan, Cesare also playing a significant role (0.0191), illustrating his importance in linking various parts of the network.

Summary

Overall, the analysis of the colonoscopy research co-authorship networks from 2000 to 2023 shows a landscape characterized by increasing but still fragmented collaborations, with several prominent researchers consistently playing central roles. From 2000 to 2009, the network was sparse and highly fragmented, with key contributors such as Byeon, Jeong-Sik (University of Ulsan College of Medicine, Seoul, Korea), and Atkin, W. (Imperial College London, St Mary's Hospital, Norfolk Place, London) emerging as central figures. In the 2010-2019 period, despite an increase in collaboration, the network remained characterized by numerous isolated components, with Hassan, Cesare (Nuovo Regina Margherita Hospital, Rome, Italy) becoming pivotal in connecting disparate groups. By 2020-2023, while the network exhibited tighter clustering and a rise in influential contributors like Hassan, Cesare (Nuovo Regina Margherita Hospital, Rome, Italy) and Dekker, Evelien (Academic Medical Centre, Amsterdam, The Netherlands), the overall structure still reflected significant fragmentation, with many independent clusters and a lack of comprehensive connectivity.

These findings underscore the ongoing potential for greater integration within the field of colonoscopy research. The persistent presence of key researchers as central connectors suggests that while collaborative efforts have intensified, there remains a substantial opportunity for further strengthening of network cohesion. Future efforts to enhance cross-group collaborations could help in bridging the existing gaps and fostering a more interconnected and robust research community.

Discussion

The present study examined the co-authorship networks within colonoscopy research, using data from the WoS Collection between 2000 and 2023. A comprehensive network analysis was conducted, applying both macro-level and micro-level metrics to understand the structure and evolution of collaborative research in this field. The results revealed notable trends and patterns in the collaborative landscape, highlighting the dynamic nature of research partnerships in colonoscopy.

At the macro level, the analysis showed that the overall network density was relatively low throughout the study period, indicating limited actualized connections compared to the potential maximum. This low density suggests that, while there are many active researchers in the field, the collaboration among them is not uniformly widespread. For instance, the network density was particularly low during the initial period (2000-2009), with a value of 0.000258, reflecting a fragmented research environment with many isolated authors and small groups rather than a cohesive, interconnected network. This fragmentation was further evidenced by the high number of components (2643) observed in the network, which consisted of numerous disconnected subgroups of researchers. As the network evolved over time, the density increased slightly in the most recent period (2020-2023) to 0.000265, suggesting a gradual strengthening of collaborative ties.

The average clustering coefficient remained high across all periods, indicating a strong tendency for authors to form tightly knit groups. For instance, the average clustering coefficient was 0.890 in 2000-2009 and slightly increased to 0.904 in 2020-2023. This finding implies that when collaborations occurred, they often involved closely interconnected clusters of researchers, which is characteristic of a field where collaboration is selective and tends to occur within specific research groups or institutions. These clusters could represent specialized subfields or research teams that frequently collaborate, potentially enhancing the quality and impact of their outputs.

The average path length, or the mean distance between nodes, was effectively infinite during all periods due to the high fragmentation of the network, highlighting that many authors were entirely disconnected from the broader network. This pattern persisted despite some reduction in fragmentation over time, indicating ongoing challenges in creating a fully cohesive collaborative network.

In terms of micro-level metrics, the analysis identified key researchers who played significant roles in the collaborative landscape of colonoscopy research. Degree centrality highlighted prominent authors who frequently collaborated, such as Byeon, Jeong-Sik (0.0044), Rex, Douglas K. (0.0042), and Lieberman, David A. (0.0038) during the 2000-2009 period. These high degree centrality scores suggest that these individuals were prolific in establishing co-authorships, making them central

figures in the network. In the subsequent periods, Hassan, Cesare emerged as a leading figure, with the highest degree centrality in both the 2010-2019 (0.0094) and 2020-2023 (0.0133) periods, reflecting his active and expanding participation in research collaborations.

Closeness centrality, which measures how close an author is to all other authors in the network, identified figures such as Atkin, W. (0.0578 in 2000-2009) and Rex, DK (0.0573 in 2000-2009) as central in terms of their accessibility within the network. High closeness centrality scores indicate that these authors were well-positioned to access and disseminate information rapidly within the network, enhancing their influence and visibility in the research community. By the 2010-2019 period, Hassan, Cesare and Dekker, Evelien dominated closeness centrality with scores of 0.1885 and 0.1849, respectively, underscoring their prominent roles in facilitating the flow of information within the collaborative network.

Betweenness centrality provided further insights into the roles of specific authors in bridging different parts of the network. Authors with high betweenness centrality, such as Atkin, W. (0.0099 in 2000-2009) and Dekker, E. (0.0547 in 2010-2019), occupied strategic positions that allowed them to act as intermediaries between otherwise unconnected groups of researchers. This bridging role is particularly valuable in facilitating the flow of information and ideas across the network, potentially leading to novel collaborations and interdisciplinary research efforts. Hassan, Cesare, who also had a high betweenness centrality score in the most recent period (0.0323 in 2010-2019), consistently acted as a key intermediary throughout the study periods.

Overall, the findings from this network analysis offer a comprehensive view of the collaborative structures within colonoscopy research over the past two decades. The identified key players and clusters highlight the critical contributors and the evolving nature of partnerships in this field. Understanding these patterns can inform strategies for enhancing collaboration, such as fostering connections between isolated components and supporting emerging researchers in establishing broader networks. Additionally, recognizing the roles of central figures and bridge-builders can help target initiatives aimed at leveraging their influence to further integrate the global research community.

The evolution of the collaborative network in colonoscopy research also reflects broader trends in scientific research, such as the increasing importance of international collaboration and the rise of interdisciplinary approaches. As the field continues to grow, there are opportunities to strengthen these networks further, especially in regions with emerging research capacities. By fostering inclusive and diverse collaborations, the field of colonoscopy research can continue to advance, ultimately contributing to improved outcomes in colorectal disease management and prevention.

In conclusion, the comprehensive analysis of the co-authorship networks in colonoscopy research has revealed both strengths and areas for improvement in the collaborative landscape. By identifying key researchers, influential clusters, and the overall network structure, this study provides valuable insights that can guide future research efforts and promote more effective and impactful collaborations in the field.

Conclusion

The co-authorship network analysis of colonoscopy research from 2000 to 2023 reveals a landscape of increasing but still fragmented collaborations among researchers. Despite the growth in the number of publications and collaborations over the years, the network's density remained consistently low across all periods, with only a small fraction of potential relationships being realized. This suggests that while researchers are willing to collaborate, the overall cohesion of the network is limited, and many potential connections remain unexplored. The high clustering coefficient observed across all periods indicates that when collaborations occur, they tend to form tightly knit groups. However, the persistence of numerous disconnected components highlights the fragmented nature of the network, with no single dominant connected component emerging.

At the micro-level, degree centrality analysis identified several key researchers who consistently played central roles in the network. During the 2000-2009 period, Byeon, Jeong-Sik (Asan Medical Center, Seoul, Korea) was among the most prominent figures, with high collaboration frequency and

central positioning within the network. In the subsequent decade (2010-2019), Hassan, Cesare (Nuovo Regina Margherita Hospital, Rome, Italy) emerged as a pivotal figure, maintaining a central position through frequent collaborations and effective connectivity with other researchers. This trend continued into the 2020-2023 period, where Hassan, Cesare (Nuovo Regina Margherita Hospital, Rome, Italy), along with Dekker, Evelien (Academic Medical Centre, Amsterdam, The Netherlands) and Repici, Alessandro (Humanitas Research Hospital, Milan, Italy), were identified as central figures who significantly influenced the network's structure and information flow.

The average distance between nodes remained infinite across all periods, reflecting the overall lack of connectivity and the presence of many isolated clusters. This highlights the need for more integrative efforts to bridge gaps between disparate research groups. Betweenness centrality metrics further emphasized the roles of key intermediaries such as Dekker, Evelien (Academic Medical Centre, Amsterdam, The Netherlands) and Hassan, Cesare (Nuovo Regina Margherita Hospital, Rome, Italy), who facilitated connections between otherwise unlinked parts of the network in the 2010-2019. These individuals not only contributed to the flow of information but also acted as critical nodes in maintaining the network's overall structure.

The study's findings underscore the importance of fostering greater collaboration and connectivity within the field of colonoscopy research. By identifying key researchers and highlighting the fragmented nature of the network, this analysis provides valuable insights into areas where collaboration can be strengthened. Enhancing connectivity between isolated research clusters could lead to more robust and impactful scientific advancements, ultimately benefiting the field as a whole. As colonoscopy remains a vital tool in colorectal disease prevention and management, continued efforts to improve collaboration and integration among researchers will be essential in addressing the ongoing challenges and advancing the field.

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Conflict of interest disclosure statement: none

Abbreviations: WoS, Web of Science; IDE, Integrated Development Environment

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