Review Article

DIGITAL HEALTH
Volume 10: 1–22

DOI: 10.1177/20552076241287460
journals.sagepub.com/home/dhj

Knowledge mapping of telemedicine in urology in the past 20 years: A bibliometric analysis (2004–2024)

Na Zeng[1,*], Mei-Cheng Liu[1,*], Xing-Yu Zhong[1], Shao-Gang Wang[1] and Qi-Dong Xia[1]

Abstract

Telemedicine refers to the process of utilizing communication technologies to exchange disease information, perform surgery and educate care providers remotely, breaking through the distance limit and promoting the health of individuals and communities. The fifth-generation (5G) technology and the COVID-19 pandemic have greatly boosted studies on the application of telemedicine in urology. In this study, we conduct a comprehensive overview of the knowledge structure and research hotspots of telemedicine in urology through bibliometrics. We searched publications related to telemedicine in urology from 2004 to 2024 on the Web of Science Core Collection (WoSCC) database. VOSviewer, CiteSpace and R package "bibliometrix" were employed in this bibliometric analysis. A total of 1,357 articles from 97 countries and 2,628 institutions were included. The number of annual publications on telemedicine in urology witnessed a steady increase in the last two decades. Duke University was the top research institution. Urology was the most popular journal, and Journal of Medical Internet Research was the most co-cited journal. Clarissa Diamantidis and Chad Ellimoottil published the most papers, and Boyd Viers was co-cited most frequently. Effectiveness evaluation of telemonitoring, cost–benefit analysis of teleconsultation and exploration of telesurgery are three main research hotspots. As the first bibliometric analysis of research on telemedicine in urology, this study reviews research progress and highlights frontiers and trending topics, offering valuable insights for future studies.

Keywords

Bibliometric, CiteSpace, telemedicine, urology, VOSviewer

Submission date: 3 June 2024; Acceptance date: 10 September 2024

Introduction

In an era when the increasing cost of health care and the inequality of access to medical resources call for a more efficient care delivery model, one promising initiative has been telemedicine. Telemedicine refers to the process of utilizing telecommunications technologies to share medical knowledge, exchange disease information, and even perform operational practice, which breaks through the distance limit and advances the health of individuals and their communities.[1] Traditional telemedicine mainly encompasses three subcategories: (1) telemonitoring, involving doctors monitoring the physiological index and physical symptoms of patients, as well as managing their health status; (2) telesurgery, allowing surgeons to perform operations by controlling surgical robot located at a distance from operating theater;[2] (3) telementoring, focusing on guidance and consultation between remote specialists and local doctors or students.

Firstly proposed by Thomas Bird in the 1970s, the concept of telemedicine received significant attention from the medical community.[3] In the United States, the success of the Space Technology Applied to Rural

[1]Department and Institute of Urology, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

*Two authors contributed equally to this work.

Corresponding authors:
Shao-Gang Wang, Department and Institute of Urology, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, No. 1095 Jiefang Avenue, 430030, Wuhan, China.
Email: sgwangtjm@163.com

Qi-Dong Xia, Department and Institute of Urology, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, No. 1095 Jiefang Avenue, 430030, Wuhan, China.
Email: qidongxia_md@163.com

Papago Advanced Health Care (STARPHAC) project marked a breakthrough in telemedicine adoption and prompted its development in the following years.[4] Over the next two decades, with the advancement of communication technologies, the adoption of telemedicine across the globe grew exponentially. In 2001, Jacques Marescaux in New York performed the first remote laparoscopic cholecystectomy on a patient in Strasbourg, verifying the feasibility of telesurgery.[5] However, the lack of official regulations, the expensive cost and the limitation of network systems impeded the practice and popularization of telemedicine in the last two decades. Until recent years, with the integration of new technologies, such as the fifth-generation (5G) internet,[6] and in response to the coronavirus disease (COVID-19) pandemic, the modern development of telemedicine has greatly boosted.[7] More subsets of telemedicine were developed, such as teletherapy, telepharmacy and telepathology, and assessments on their implementation and outcomes were conducted.[8–10]

To date, telemedicine has been used in a wide array of medical fields, especially in urology due to three advantages. First, the diagnosis of urological diseases relies more on the assessment of imaging data. Differences in experience exert no obvious effect on the result of urological physical examinations, which compensates for the inability of experts in remote locations to conduct physical examinations in person. Second, the anatomical positions of urinary system organs are relatively fixed, making remote surgery less challenging compared to surgeries on organs with greater variability. Third and most critically, urology has led the way in the development of telerobotic surgery.[11] In 1995, Intuitive Surgical was founded and introduced the first da Vinci robotic surgical system to the market in 1999.[12] In 2001, the first cases of robot-assisted radical prostatectomy were performed in Europe. In 2005, Vattikuti Institute completed 2005 robotic prostatectomies, symbolizing the largest single experience of robotic surgery internationally, catapulting urology into the premier surgical robotic specialty.[13] Since then, robotic systems have been widely used in urology and are best versed in surgery of the kidney, prostate and bladder.[14]

Bibliometrics is a systematic examination method that uses statistical, data mining and visualization techniques to quantitatively analyze scientific literature. It aimed at identifying patterns, trends and impact within a particular field.[15,16] Specifically, the evaluation comprises information about authors, countries, journals, institutions, references and keywords. Compared to traditional systematic reviews, bibliometric analysis offers distinct advantages, such as providing a broad quantitative overview of research trends and impacts and enabling the identification of emerging fields and influential studies with greater efficiency.[17,18] By applying bibliometrics to analyze the research progress of medical issues, valuable reference information can be provided to clinicians to guide clinical practice and improve treatment protocols. Additionally, this analytical approach contributes to facilitating academic exchanges, enhancing patient education levels and driving continuous development and innovation.[19] Bibliometric tools, such as CiteSpace, VOSviewer, and R package "bibliometrix," are commonly utilized to visualize the results,[20] offering a dynamic and comprehensive view of research patterns and connections.

Existing research in the past two decades has drawn contradictory conclusions on the effect of telemedicine in urology. Technology advancement also altered the challenges and limitations of telemedicine over time. Furthermore, bibliometric research on telemedicine associated with urology remained empty. Therefore, this study performed a bibliometric analysis of existing publications, leveraging its advantages over traditional reviews to provide possible explanations for the inconsistent outcomes and serving as a reference study for future studies to validate the effect of telemedicine.

Methods

Data collection

We conducted a literature search using the Web of Science Core Collection (WoSCC) database (https://www.webofscience.com/wos/woscc/basic-search) on 17 July, 2024. The search terms consisted of two parts: the first part focused on telemedicine with terms, such as "telemedicine", "telehealth" and "telecommunication"; the second part encompassed terms associated with urologic non-tumorous diseases and neoplastic diseases, including kidney cancer, bladder cancer and prostate cancer. The detailed search terms are listed in the Supplemental Material. Publication years were limited from 1 January, 2004 to 17 July, 2024. The type of documents was set to "article" and "review article." Documentations in non-English were excluded. The detailed flowchart is provided in Figure 1.

Data analysis

Microsoft Office Excel 2019 was used to conduct data analysis and to visualize the annual number of publications. VOSviewer (version 1.6.20) can extract information from literature and explore relationships among relevant academic fields.[21] In our study, VOSviewer was utilized to investigate networks for country, institution, journal, author and keyword analysis. CiteSpace (version 6.2.R7) was used to construct a dual-map overlay of journals and to analyze references with citation bursts. The R package "bibliometrix" (version 4.0.0) (https://www.bibliometrix.org) was applied for a global distribution network of publications and trend topic analysis.[22] The quartile and impact factor of the journal were obtained from Journal Citation Reports 2023.

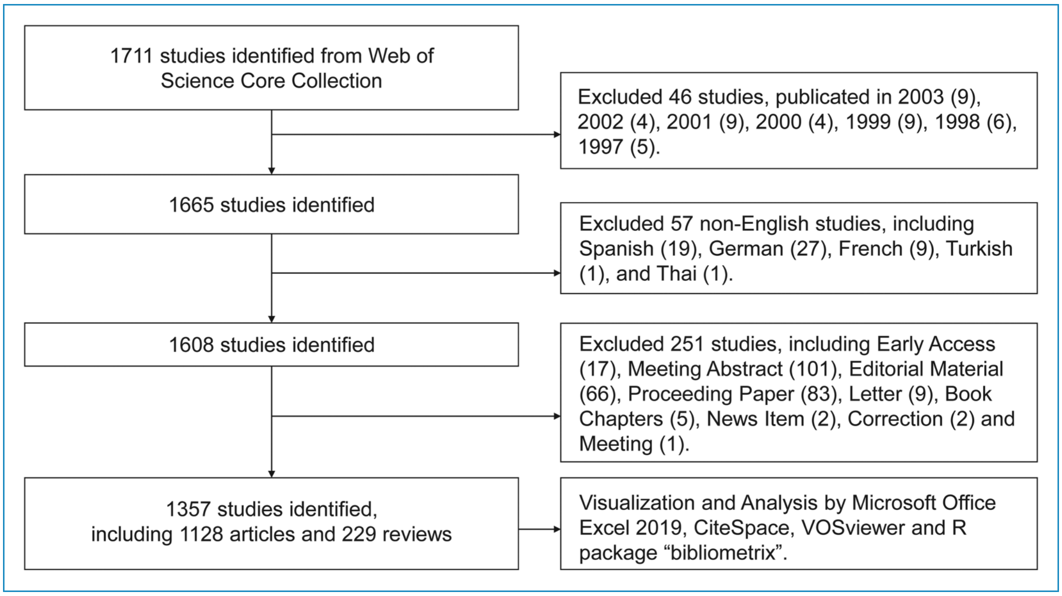

Figure 1. Publications screening flowchart.

Results

Quantitative analysis of publications

The number of publications over a period can reflect the research speed and trend in a field. A total of 1,357 studies from 1 January, 2004 to 17 July, 2024 were included. The whole period can be divided into three periods shown in Figure 2. Few studies focused on telemedicine in urology in Period I with an average annual publication number of less than eight, representing that it has garnered a novel beginning. From 2011 to 2019, the number witnessed a gentle, but steady growth. In 2020, the number spiked almost twice, indicating a high interest in this field. In Period III, the number of publications has remained constant around 200 from 2020 to 2023, with 93 publications in the past 7 months in 2024, demonstrating a burgeoning attention on telemedicine in urology.

Countries and institutions

These publications originated from 97 countries and 2,628 institutions. The largest number of publications was from the United States, the United Kingdom and China, accounting for 44.4%, 10.8%, and 9.2% of the total counts, respectively (Table 1). The combined number of publications from the United States and the United Kingdom accounted for more than half of the total (55.2%). A connection network was visualized in Figure 3(A) based on literature from 46 countries, with a minimum number of five documents. The United States displayed a close relationship with most countries such as Germany, Canada, China and the United Kingdom. Notably, Ireland only collaborated with the United States. The average publication year of the United States, the United Kingdom, Germany and other European countries has fallen between 2019 and 2020, while many Asian countries, such as China, Malaysia, and India have not conducted concentrated studies until 2021 or even 2022.

The top 10 institutions are distributed in three countries, with six of them located in the United States. Duke University ($n = 39$, 2.9%), University of Washington ($n = 33$, 2.4%), University of Toronto ($n = 33$, 2.4%) and University of Michigan ($n = 33$, 2.4%) ranked top 4. Subsequently, we selected 174 institutions based on the minimum number of publications equal to five and constructed a collaborative network (Figure 3(B)).

Journals and co-cited journals

Relevant publications were published in 556 journals. Urology ($n = 41$, 3.0%) published the most papers, followed by Journal of Medical Internet Research ($n = 28$, 2.1%) and BMJ Open ($n = 26$, 1.9%) (Table 2). The journal with the highest impact factor was American Journal of Kidney Diseases (IF = 9.4). 12 journals were categorized in Q1 and Q2, while the left three journals were not included in the latest JCR journal citation report. Subsequently, we mapped the network of 60 journals based on the minimum number of publications equal to 5 (Figure 4(A)). Intriguingly, several journals in the yellow and red clusters were related to kidney disease, such as Journal of Renal Nutrition, Kidney Medicine and American Journal of Kidney Diseases, etc.

The right part of Table 2 displayed the top 15 co-cited journals. Two journals were co-cited more than 800 times. Journal of Medical Internet Research (co-citation = 914) was the most

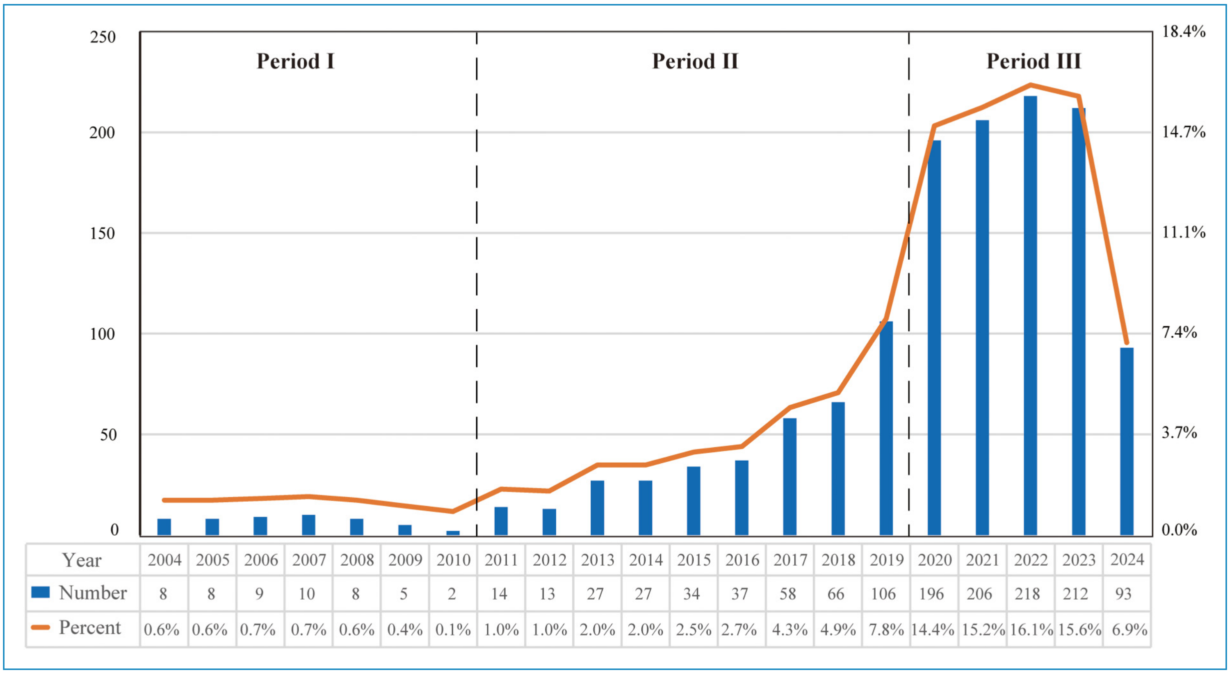

Figure 2. Annual number of publications on telemedicine in urology.

Table 1. Top 10 countries and institutions on research of telemedicine in urology.

Rank	Country	Counts	Institution	Counts
1	United States (North America)	603(44.4%)	Duke University (United States)	39(2.9%)
2	United Kingdom (Europe)	147(10.8%)	University of Washington (United States)	33(2.4%)
3	China (Asia)	125(9.2%)	University of Toronto (Canada)	33(2.4%)
4	Australia (Oceania)	112(8.3%)	University of Michigan (United States)	33(2.4%)
5	Canada (North America)	105(7.7%)	University of California, San Francisco (United States)	30(2.2%)
6	Italy (Europe)	79(5.8%)	The University of Sydney (Australia)	27(2.0%)
7	Germany (Europe)	62(4.6%)	The University of Queensland (Australia)	25(1.8%)
8	India (Asia)	60(4.4%)	University of Melbourne (Australia)	24(1.8%)
9	Netherlands (Europe)	57(4.2%)	Mayo Clinic (United States)	23(1.8%)
10	Spain (Europe)	50(3.7%)	Northwestern University (United States)	23(1.7%)

co-cited journal, followed by American Journal of Kidney Disease (co-citation = 803) and Journal of Urology (co-citation = 785). The impact factor of Lancet was the highest (IF = 98.4), followed by New England Journal of Medicine (IF = 96.2) and JAMA-Journal of the American Medical Association (IF = 63.1). Journals with a minimum co-citation equal to 20 were filtered to map the co-citation network (Figure 4(B)). The size of the visualization circle is determined by the strength of the journal's connections with others. Diabetes Care had positive co-citation relationships with the abovementioned three high-IF journals as well as the largest link strength with other journals.

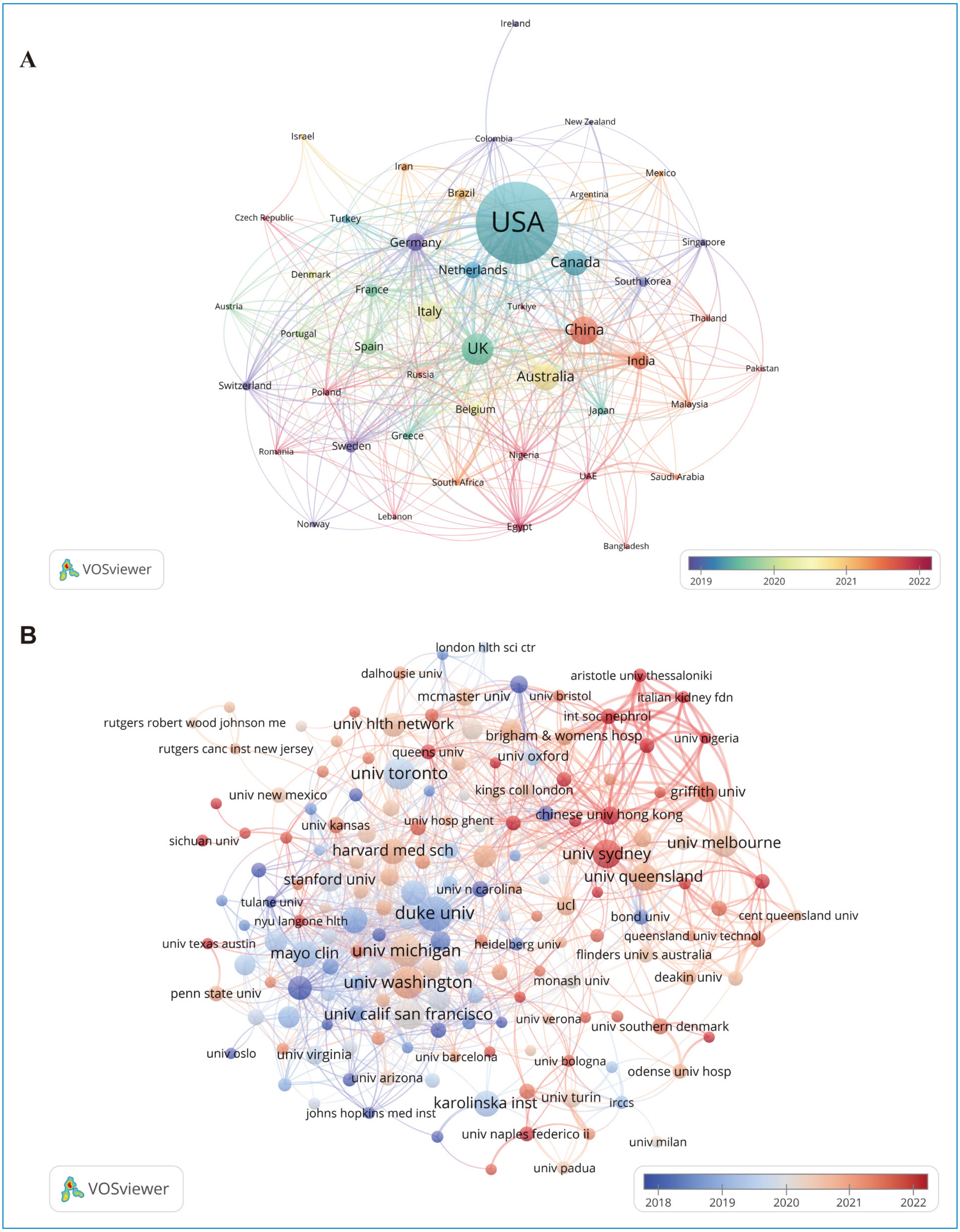

Figure 3. The visualization of countries (a) and institutions (b) on research of telemedicine in urology.

Table 2. Top 15 journals and co-cited journals on research of telemedicine in urology.

Rank	Journal	Count	IF	Q	Co-cited journal	Co-citation	IF	Q
1	Urology	41(3.0%)	2.1	Q2	Journal of Medical Internet Research	914	5.8	Q1
2	Journal of Medical Internet Research	28(2.1%)	5.8	Q1	American Journal of Kidney Disease	803	9.4	Q1
3	BMJ Open	26(1.9%)	2.4	Q1	Journal of Urology	785	5.9	Q1
4	Urology Practice	25(1.8%)	0.8	NA	European Urology	752	25.3	Q1
5	Telemedicine and E-health	24(1.8%)	2.8	Q2	Urology	698	2.1	Q2
6	JMIR Mhealth and Uhealth	22(1.6%)	5.4	Q1	The New England Journal of Medicine	694	96.2	Q1
7	BMC Nephrology	19(1.4%)	2.2	Q2	JAMA-Journal of the American Medical Association	598	63.1	Q1
8	PLoS One	18(1.3%)	2.9	Q1	Lancet	591	98.4	Q1
9	Journal of Telemedicine and Telecare	17(1.3%)	3.5	Q1	Kidney International	559	14.8	Q1
10	Canadian Journal of Kidney Health and Disease	15(1.1%)	1.6	NA	Journal of Telemedicine and Telecare	555	3.5	Q1
11	Journal of Urology	14(1.0%)	5.9	Q1	PLoS One	520	2.9	Q1
12	Sensors and Actuators B-Chemical	14(1.0%)	8.0	Q1	Clinical Journal of the American Society of Nephrology	505	8.5	Q1
13	World Journal of Urology	14(1.0%)	2.8	Q2	Diabetes Care	456	14.8	Q1
14	JMIR Research Protocols	13(1.0%)	1.4	NA	Journal of Clinical Oncology	426	42.1	Q1
15	American Journal of Kidney Diseases	12(0.9%)	9.4	Q1	BJU International	395	3.7	Q1

The dual-map overlay mapped out the intricate web of citation relationships between journals and co-cited journals, displaying citing journals on the left side and cited journals on the other side. In Figure 5, research in Health/Nursing/Medicine journals was frequently cited by Medicine/Medical/Clinical journals.

Authors and co-cited authors

More than 8,093 authors had participated in the research on telemedicine in urology. Both Clarissa Diamantidis and Chad Ellimoottil had published 11 papers, followed by Katrina Campbell and Jaimon Kelly with 10 papers per capita (Table 3). We built a collaborative network based on the minimum papers of five (Figure 6(A)). Strong collaborations among several groups were observed. For example, Katrina Campbell, Jaimon Kelly and Allison Tong had close cooperation with each other in the orange cluster.

Among the 33,043 co-cited authors, five authors were co-cited more than 65 times (Table 3). The most co-cited author was Boyd Viers ($n = 77$), followed by the World Health Organization ($n = 77$). Authors with minimum co-citations equal to 20 were filtered to map the co-citation network (Figure 6(B)). Similarly, active collaborations of several groups were observed among co-cited authors, such as Boyd Viers, Stephanie Chu and Chandy Ellimoottil in the blue cluster.

Co-cited references

Co-cited references analysis indicates that two references are cited in the reference list of a third article. As depicted in Table 4, the top two co-cited references were both from European Urology, with citations of 55 and 48. We selected references with a minimum co-citation of 20 for constructing the co-citation network (Figure 7). “Viers Br, 2015, Eur Urol” showed active co-cited relationships with “Chu S, 2015, Urology,” and “Ellimoottil C, 2016, Urology,” etc., consistent with the bibliometric mapping relationship of the co-citation authors.

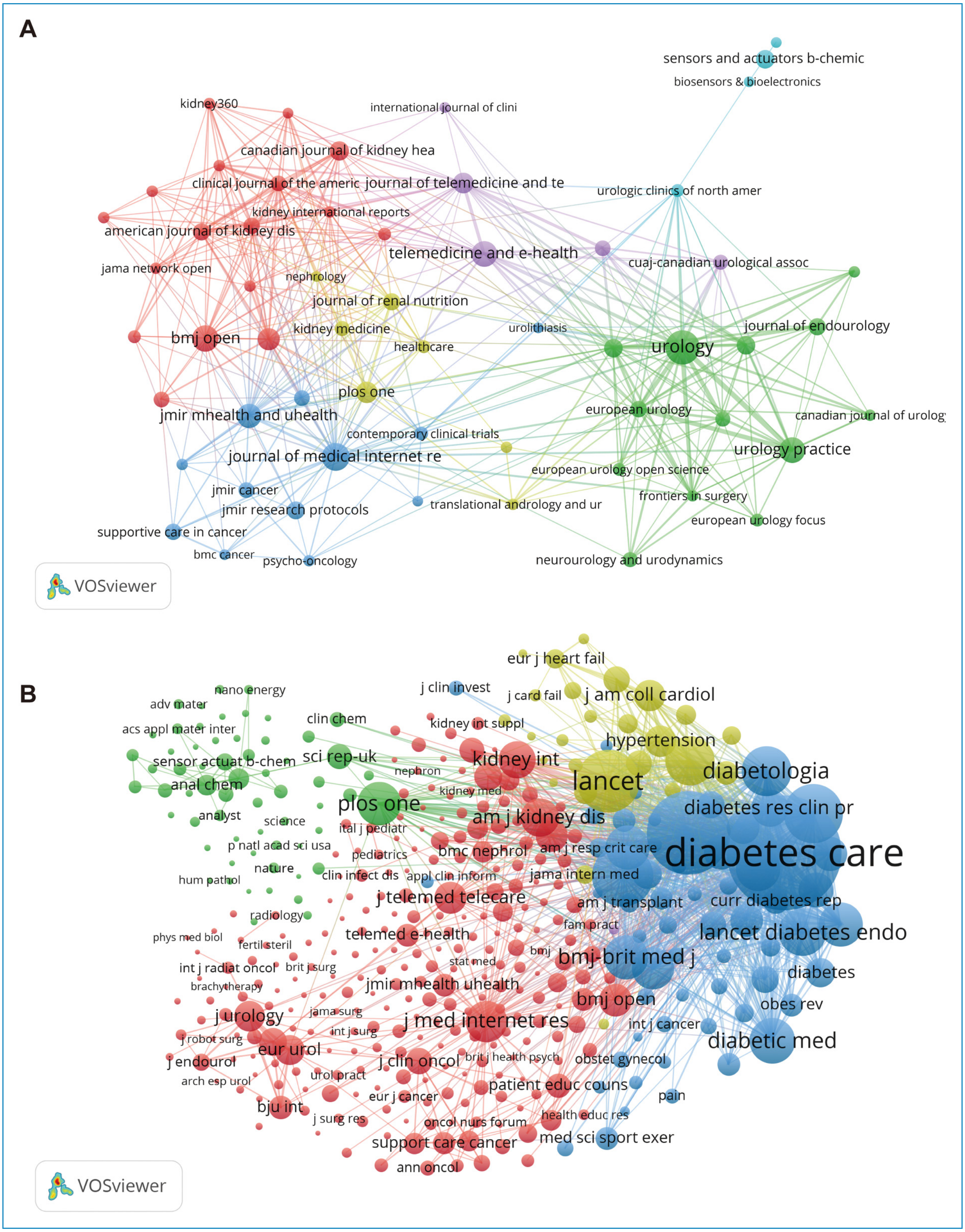

Figure 4. The visualization of journals (a) and co-cited journals (b) on research of telemedicine in urology.

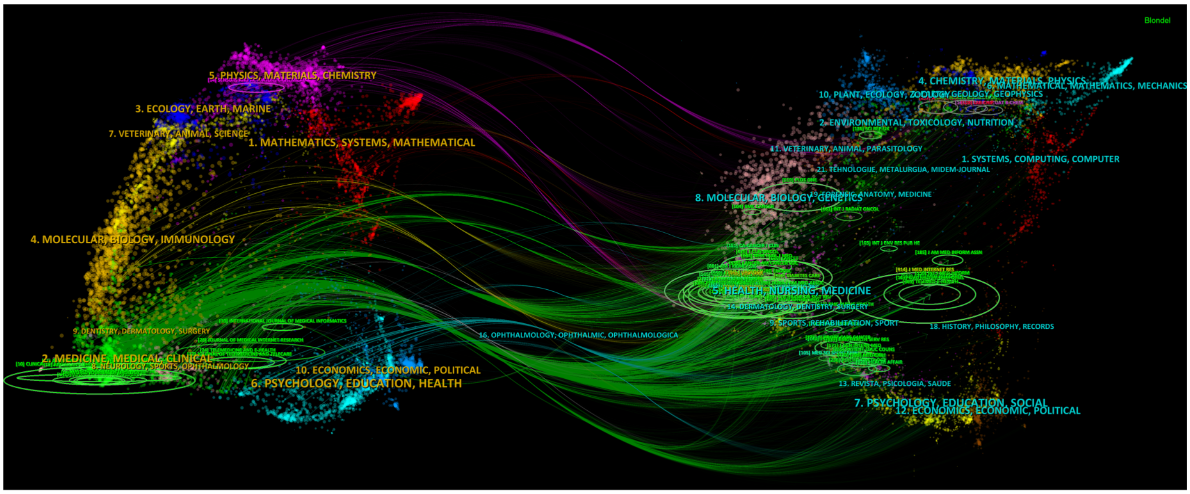

Figure 5. The dual-map overlay of journals on research of telemedicine in urology.

Table 3. Top 10 authors and co-cited authors on research of telemedicine in urology.

Rank	Authors	Count	Co-cited authors	Citations
1	Clarissa Diamantidis	11	Boyd Viers	77
2	Chad Ellimoottil	11	World Health Organization	77
3	Katrina Campbell	10	Susie Lew	67
4	Jaimon Kelly	10	Clarissa Diamantidis	66
5	Frank Penedo	9	Andrew Levey	66
6	Aminu Bello	8	Adam Gadzinski	53
7	Hayden Bosworth	8	Allison Tong	52
8	Susie Lew	8	Gunther Eysenbach	50
9	Allison Tong	7	Katharina Boehm	48
10	Ann Bonner	7	Chad Ellimoottil Mani Menon	48

References with citation bursts

References with citation bursts refer to references that experience a surge in citations over a specified timeframe. A total of 25 references with strong citation bursts were identified by CiteSpace and sorted in chronological order of the beginning year of citation bursts (Figure 8). The burst strength ranged from 4.05 to 8.00, and endurance strength was from 2 to 4 years. The reference with the strongest citation burst (strength = 8.00) was titled "Telemedicine Online Visits in Urology During the COVID-19 Pandemic-Potential, Risk Factors, and Patients' Perspective,"[23] authored by Katharina Boehm et al., with citation burst from 2017 to 2019. The reference with the second strongest citation burst (strength = 7.53) was titled "Health information technology (IT) to improve the care of patients with chronic kidney disease (CKD),"[24] authored by Clarissa Diamantidis et al., with citation burst from 2017 to 2019. Table 5 summarizes the main research contents of the 25 references.

Hotspots and frontiers

As displayed in Table 6, we tended to divide author keywords into mainly two categories: disease-related keywords and telemedicine-related keywords. Keywords concerning kidney diseases, such as chronic kidney disease (occurrence = 135), dialysis (occurrence = 41), diabetic kidney disease (occurrence = 34), nephrology (occurrence = 21) and kidney transplantation (occurrence = 20), had received a relatively high total occurrence, followed by prostate cancer (occurrence = 121). Telemedicine-related keywords comprised e-health (occurrence = 108), m-health (occurrence = 99), telesurgery (occurrence = 20), etc. Other high-frequency keywords included COVID-19 (occurrence = 135) and randomized controlled study (occurrence = 25).

We filtered the top 49 author keywords with a minimum occurrence number of 13 and performed cluster analysis (Figure 9(A)). We obtained five clusters in red, purple, blue, green and yellow, representing the main research directions.

Trend topic analysis (Figure 9(B)) showed that in Period I (2004–2010), research probably focused on the initial attempt of virtual reality technology on urological surgery

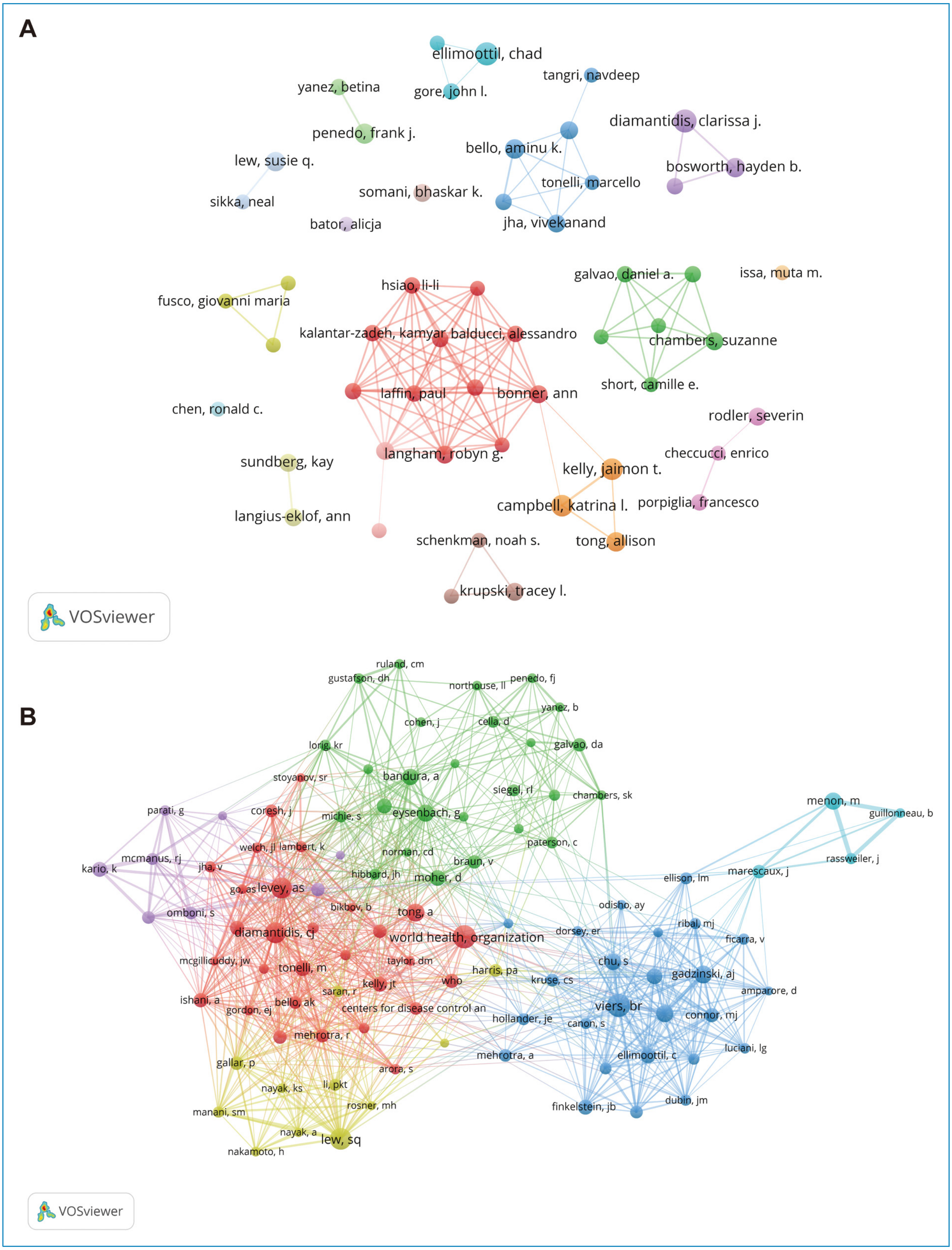

Figure 6. The visualization of authors (a) and co-cited authors (b) on research of telemedicine in urology.

Table 4. Top 10 co-cited references on research of telemedicine in urology.

Rank	Co-cited reference	Main research content	Citations
1	Viers BR, 2015, Eur Urol, V68, P729[1]	A randomized controlled trial found equivalent efficiency, similar satisfaction, but significantly reduced patient costs for video visit technology compared to traditional office visits following radical prostatectomy.	55
2	Boehm K, 2020, Eur Urol, V78, P16[2]	A review discussed the potential, risk factors and patients' perspective of telemedicine online visits in urology during the COVID-19 pandemic.	48
3	Chu S, 2015, Urology, V86, P255[3]	A retrospective chart review examined care delivered through urology telemedicine clinics over a 6-month period.	45
4	Novara G, 2020, Eur Urol, V78, P786[4]	A systematic review of the literature evaluated the potential of telemedicine during and after the COVID-19 pandemic.	38
5	Ishani A, 2016, Am J Kidney Dis, V68, P41[5]	A randomized controlled trial proposed that there was no statistically significant evidence of superiority of telehealth by an interprofessional team on health outcomes compared to usual care in chronic kidney disease patients.	34
6	Gallar P, 2007, J Telemed Telecare, V13, P288[6]	A 2-year experience proposed that home telemedicine appeared to be clinically useful in the long-term follow-up of stable patients undergoing peritoneal dialysis, and the costs and savings also seemed to be encouraging.	31
7	Ellimoottil C, 2016, Urology, V94, P10[7]	A review discussed the application and prospect of televisits and teleconsultations in urology.	30
8	Tong A, 2007, Int J Qual Health C, V19, P349[8]	An introduction of consolidated criteria for reporting qualitative research (COREQ), a 32-item checklist for interviews and focus groups, including three domains: (i) research team and reflexivity, (ii) study design and (iii) data analysis and reporting	30
9	Moher D, 2010, Int J Surg, V8, P336[9]	Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement	29
10	Hollander Je, 2020, New Engl J Med, V382, P1679[10]	An introduction of telemedicine for COVID-19	28

including nephrectomy and laparoscopic radical prostatectomy. From 2011 to 2019 (Period II), teleconsultation by online connection witnessed a high trend. Over the recent years (2020–2024), topics related to chronic disease management, including quality of life, chronic kidney disease and prevention had frequently appeared.

Discussion

General information

The number of publications exhibited an overall growth trend. From 2004 to 2010, research in this field was still in its infancy. As technological infrastructure evolves, studies on telemedicine in urology had a steady rise from 2011 to 2019. The number of publications in 2017 had a 50% growth from last year, which may be attributed to the rise of 5G technology in 2016, when Qualcomm announced the first 5G modem, while Huawei (China) and DOCOMO (Japan) declared the first large-scale trial of 5G network worldwide. Subsequently, two factors may account for the dramatic increase from 2019 to 2020. One is the utilization of 5G technology for commercial purposes, offering more reliable and faster connections and providing technological possibilities for the advancement of telemedicine. Its transmission capacity of up to 10 gigabits per second (Gbps) especially enables growth in high-quality remote training, offering patients the option of being treated remotely by experts. The other is the outbreak of the COVID-19 pandemic, leading to numerous precautions, including social isolation, quarantine policies and lockdown limitations.[25] In this case, telemedicine, which emphasizes on non-contact patient care, allows providing healthcare remotely and has emerged as an indispensable choice. As COVID-19 subsides, the interest of urologists seems to be shifting toward telesurgery, particularly fueled

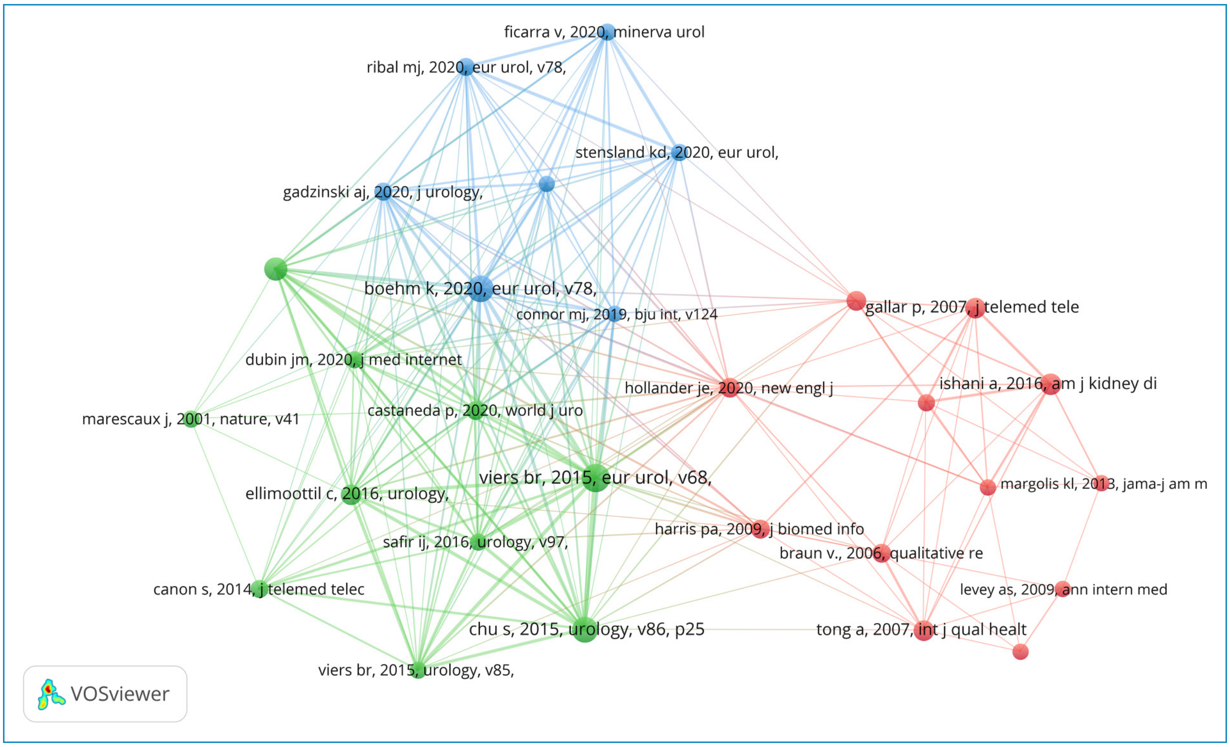

Figure 7. The visualization of co-cited references on research of telemedicine in urology.

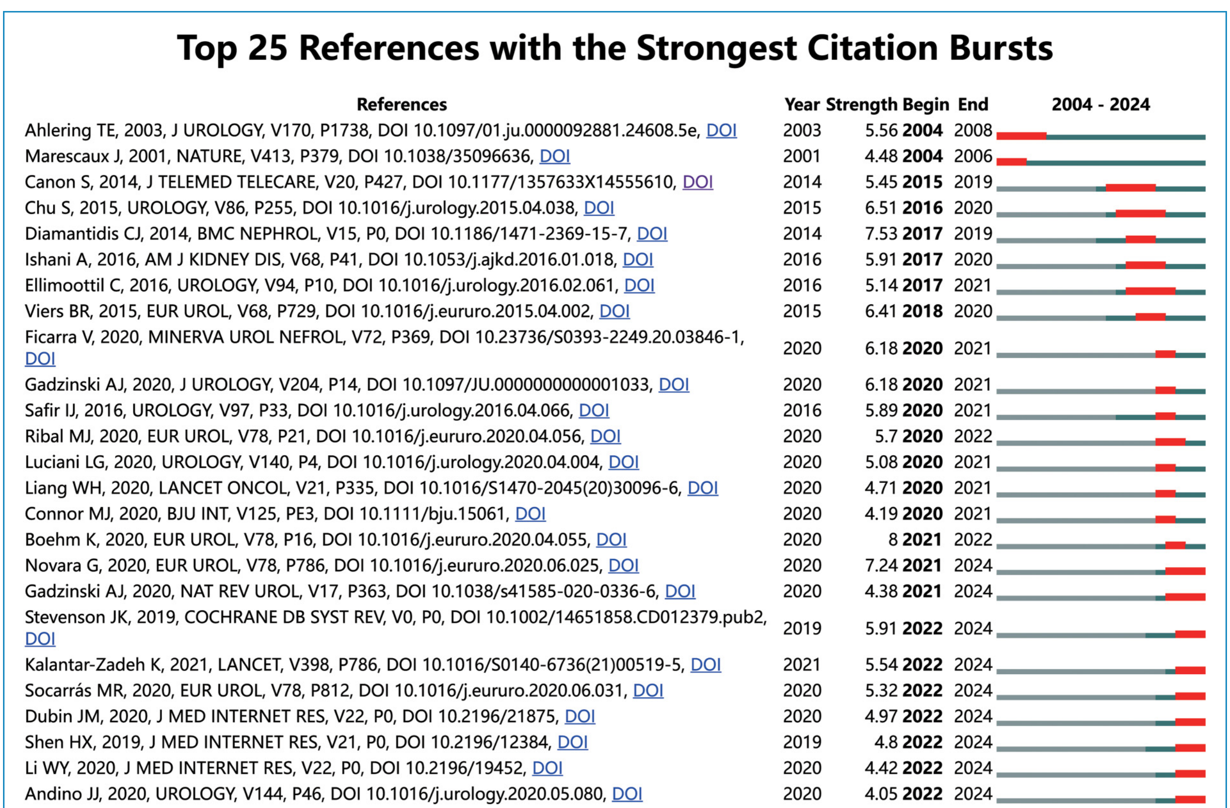

Figure 8. Top 25 references with strong citation bursts. The red bar indicates high citations in that year.

Table 5. Main research contents of the 25 references with strong citations bursts.

Rank	Strength	Main research content
1	5.56	The initial successful experience with robot-assisted laparoscopic radical prostatectomy of surgeons[1]
2	4.48	One experiment of transatlantic robot-assisted laparoscopic cholecystectomy (gall bladder removal) on a pig[2]
3	5.45	A pilot study of telemedicine for post-operative urological care in children, supporting the use of telemedicine for the post-operative evaluation of pediatric urology surgery patients and suggesting that substantial travel distance and time savings can be made.[3]
4	6.51	A retrospective chart review found that telemedicine was successfully and safely used to evaluate and treat a wide range of urologic conditions within the Veterans Affairs Greater Los Angeles Healthcare System, saving patients nearly 5 h and up to $193 per visit over a 6-month period.[4]
5	7.53	A review explored the current and potential uses of health IT platforms to advance kidney disease care by offering innovative solutions to inform, engage and communicate with individuals with CKD.[5]
6	5.91	A randomized controlled trial found that there was no statistically significant evidence of superiority of this intervention on health outcomes compared to usual care in patients with CKD.[6]
7	5.14	A review discussed the application and prospect of televisits and teleconsultations in urology.[7]
8	6.41	A randomized controlled trial found equivalent efficiency, similar satisfaction, but significantly reduced patient costs for video visit technology compared to traditional office visits following radical prostatectomy.[8]
9	6.18	Suggestions on urology practice during the COVID-19 pandemic from Italian urologists.[9]
10	6.18	A recommendation of implementing telehealth during the COVID-19 pandemic.[10]
11	5.89	A survey reported high acceptance and satisfaction of patients with telephone clinics as a mechanism for expedited hematuria evaluation, primarily due to avoiding barriers related to transportation and clinical operations, as well as a perceived high quality of evaluation.[11]
12	5.70	Recommendations to guide urologist surgeons during the COVID-19 pandemic.[12]
13	5.08	The implementation and outcomes of telemedicine in a Department of Urology in a regional hospital in Northern Italy during the COVID-19 pandemic.[13]
14	4.71	A nationwide analysis of cancer patients in SARS-CoV-2 infection in China.[14]
15	4.19	A comment on the virtual urology clinic for the cancer pathway during the Covid-19 pandemic.[15]
16	8.00	A prospective structured phone interviews of urological patients found that most patients wished for a telemedical consultation during the COVID-19 pandemic.[16]
17	7.24	A systematic review of the literature evaluated the potential of telemedicine during and after the COVID-19 pandemic.[17]
18	4.38	A recommendation of implementing telehealth during the COVID-19 pandemic.[18]
19	5.91	A review discussed the benefits and harm of using eHealth interventions for people with chronic kidney disease.[19]
20	5.54	A review introducing chronic kidney disease.[20]
21	5.32	Practical recommendations for effective use of technological tools in urology during and after the COVID-19 pandemic.[21]

(continued)

Table 5. Continued.

Rank	Strength	Main research content
22	4.97	A global, cross-sectional, web-based survey on telemedicine usage among urologists during the COVID-19 pandemic found that urologists' usage of telemedicine nearly tripled, demonstrating their ability to adopt and adapt telemedicine into their practices, but barriers involving the technology itself are still preventing many from utilizing it despite increasing interest.[22]
23	4.80	A systematic review evaluating electronic health self-management interventions for patients with chronic kidney found that outcomes closely related to the scope and duration of the intervention implemented were most likely to be impacted, while most studies evaluated only distal outcomes and thereby failed to capture intervention effects that might contribute to long-term health improvement.[23]
24	4.42	A prospective randomized controlled study found the use of wearable devices, a health management platform and social media support not only strengthened self-efficacy and self-management, but also improved quality of life and a slower eGFR decline in people with CKD at stages 1–4.[24]
25	4.05	A retrospective study concluded that video visits can be used to deliver care across a broad range of urologic diagnoses and can serve as a substitute for clinic visits.[25]

by the proliferation of surgical robots. Furthermore, reimbursement policies that include telemedicine services in insurance coverage and offer favorable reimbursement rates encourage patients and providers to adopt telemedicine. The development of clear guidelines and policies that balance innovation with patient welfare and fiscal responsibility is crucial for the sustainable growth of telemedicine in urology. In recent years, the number of publications remained high. Thus, it is predictable that the field of telemedicine in urology will continue to garner increasing interest.

Countries from North America, Europe and Asia almost accounted for the top 10 contributing countries to the research of telemedicine in urology. The United States took a dominant place based on not only the total publications ($n = 603$, 44.4%), but also the strongest cooperation with other countries, especially some European countries, such as the United Kingdom, Italy, Netherlands and Germany, all of which also performed prominently the number of publications. It is probably attributed to the effort of the American Telemedicine Association (ATA), which took the lead in drawing up regulations for telemedicine in clinical practice.[26–30] Besides, the United Kingdom took the second place in the top 10 countries' list. Benefiting from the establishment and popularization of GP at Hand, the United Kingdom gained considerable achievement in online health care provision,[31] which helped the practice and research on telemedicine in England. As for China, though there were no institutions from China in the top 10 institutions, China ranked third among the top 10 countries based on the number of publications, which was recognized as a result of its great effort in combating the COVID-19 pandemic, including the development of the internet and mobile applications as well as the progress in medical practice. Additionally, good cooperative relationships were observed among Duke University, University of Washington and University of Michigan, all of which are located in the United States. It was undeniable that active collaborations benefit the high status of the United States. More cooperation between countries and institutions is encouraged both on the information and technology levels. For example, the reliability of one mature remote application benefits from being tested based on multi-source databases of patients' information.

Research on telemedicine in urology was mostly published in Urology, which made it the most influential specialty journal in this research field. Most journals performed well in Quartile in Category with three journals not included in the latest Journal Citation Reports. This phenomenon reflected an uneven situation of telemedicine in urology, as well as a broad developing space requiring more high-quality research. Notably, the term "kidney disease" frequently appeared in the bibliometric map of journals with red and yellow clusters (Figure 4(A)), which supported a wide application of telemedicine in kidney diseases.[32] Besides, the journal cluster in light blue reflected the need to develop applications for telemedicine in urology, and the dark blue cluster represented the combination of internet and clinical management, both of which were important underlying infrastructure in this research field. The large number of publications in Physics/Materials/Chemistry shown in Figure 5 proved the point. Additionally, the terms "diabetes" and "hypertension" obviously appeared in the map of co-cited journals (Figure 4(B)), which may attributed to the strong relationship between diabetes/hypertension and secondary kidney disease, indicating the focus of telemedicine on the application of mobile health intervention in

Table 6. Top 30 keywords on research of telemedicine in urology.

Rank	Keywords	Counts	Rank	Keywords	Counts
1	Telemedicine	279	16	Peritoneal dialysis	32
2	Chronic kidney disease	135	17	Quality of life	32
3	COVID-19	135	18	Hypertension	29
4	Telehealth	131	19	Randomized controlled trial	25
5	Prostate cancer	112	20	Robotic surgery	24
6	e-health	108	21	Exercise intervention	23
7	m-health	99	22	Pandemic	23
8	Urology	85	23	Internet	22
9	Mobile application	50	24	Mobile phone	22
10	Smartphone	46	25	Physical activity	22
11	Self-management	43	26	Nephrology	21
12	Dialysis	41	27	Kidney transplantation	20
13	Cancer	40	28	Telesurgery	20
14	Digital health	38	29	Hemodialysis	19
15	Diabetic kidney disease	34	30	Kidney disease	19

diabetic kidney disease (DKD) and chronic kidney disease (CKD).[33]

Both Clarissa Diamantidis and Chad Ellimoottil published 11 papers, mainly focusing on the management effectiveness of telehealth in DKD and the economic benefits of telemedicine in urologic consultation services, respectively. The Slow Progression of Diabetic Kidney Disease (STOP-DKD) study, an RCT, was conducted to evaluate the effectiveness of remote medication management in several DKD patients and several dimensions, including glomerular filtration rate (GFR) decrease, blood pressure fluctuations, blood glucose monitoring and urinary albumin excretion record.[34–38] All the results concluded a remarkable effectiveness of telemonitoring in DKD management. Chad Ellimoottil conducted several retrospective studies, indicating that remote video consultations and follow-ups have reduced the costs for patients and are feasible in urology,[39–46] supporting the promotion of telementoring in urology outpatient services. Katrina Campbell and Jaimon Kelly jointly published 10 papers, admiring the utilization of a reliable telehealth-delivered dietary coaching program for CKD management. Based on two cross-sectional studies,[47,48] two pilot randomized controlled trials, named ENTICE-CKD trial,[49,50] one focus group study,[51] one qualitative interview study,[52] one mixed-methods process evaluation[53] and one review,[54] they recommended CKD patients to accept telehealth coaching as a way of self-management.

As for author co-citation analysis, Boyd Viers was the most frequently cited author, who specialized in radical prostatectomies.[55,56] In 2015, Boyd Viers et al. published a prospective randomized controlled study and proposed that video visits were associated with equivalent efficiency, similar satisfaction and significantly lower patient costs when compared to office visits,[57,58] which was also the most co-cited reference shown in Table 4. Intriguingly, as a global official organization, the World Health Organization ranked second in the co-citation author list. It provided several guidance for telemedicine in urology,[59,60] laying a solid foundation for future collaboration across countries and institutions.

Knowledge base

Ten co-cited references were selected based on the number of co-citations, which revealed the foundational work of the development of telemedicine in urology. Among them,

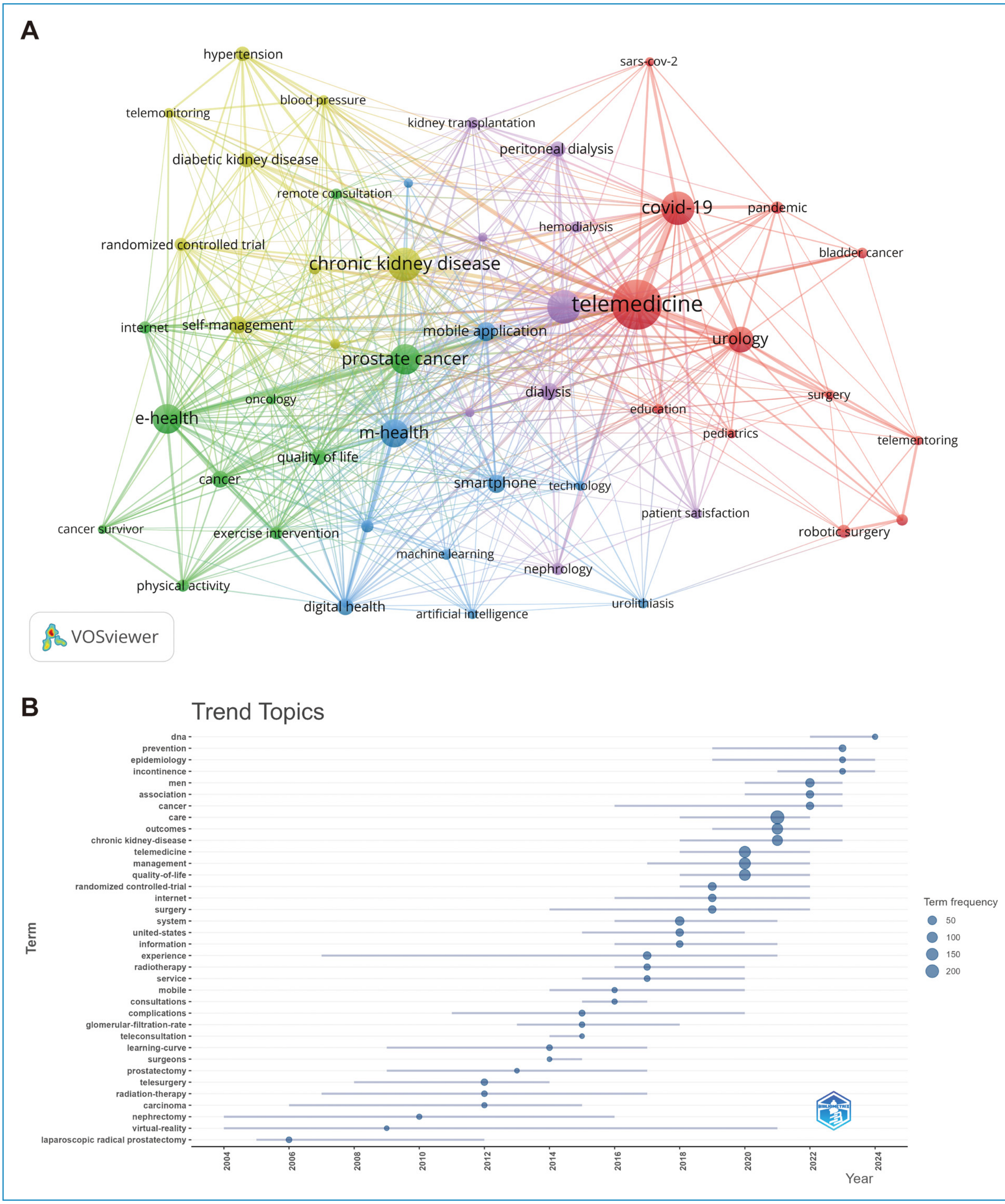

Figure 9. Keyword cluster analysis (a) and trend topic analysis (b).

three references[23,61,62] focused on the positive relationship between the occurrence of the COVID-19 pandemic and the development of telemedicine in urology, which accounted for the explosive increase of related publications in 2020. They all affirmed the successful implementation of telemedicine during the COVID-19 pandemic and at the same time emphasized more studies were needed to guarantee a safe and satisfactory outcome. The references ranked 1, 2 and 6 have affirmed the effectiveness of video consultations, remote nursing and remote dialysis management, respectively.[23,58,63] However, the fifth reference by Ishani A et al., a randomized trial, suggested that compared to usual care for CKD patients, interprofessional telemedicine teams did not demonstrate statistically significant advantages in terms of health outcomes.[64]

Evaluation on included publications

A cursory screening was taken on 1,357 publications consisting of 919 articles and 197 reviews, with the compliance of each with scientific norms confirmed. Twelve journals among the top 15 journals on telemedicine in urology were categorized in Q1 and Q2, with the high quality of the top 15 co-citation journals showing a qualified research environment. Additionally, the eighth and ninth co-cited articles introduced the consolidated criteria for reporting qualitative research (COREQ) and the PRISMA standards, respectively. The term "randomized controlled trial" ranked 19th in the top 30 author keywords. Both results demonstrate that the primary research studies on telemedicine in urology followed strict guidelines, which to a certain extent, validates the reliability of articles within this field. However, several studies focusing on the evaluation of patient satisfaction and cost benefits were constructed based on questionnaires, which were inevitable for subjective bias.

Hotspots and frontiers

According to the citation burst period (Figure 8) and the main research contents of references (Table 5), the early citation burst was driven by two references related to telesurgery and surgical procedures.[5,65] Ten references referred to the COVID-19 pandemic.[23,66–74] Although the concept of teleconsultation was proposed in 2015,[58] the outbreak of the COVID-19 pandemic motivated substantial interest in the integration of telehealth into routine urological practice, leading to more recommendations and review articles. The remaining references[24,58,64,75–84] focused on experiences or experiments that evaluated the application of telemedicine, particularly in the management of CKD patients.

As the keyword occurrence analysis shown in Table 6 implies, the application of telemedicine in urology focused mainly on kidney disease, followed by prostate cancer, both of which are considered heavy health burdens among urological disorders. According to the author keyword cluster analysis (Figure 9(A)), we obtained five clusters in red, purple, blue, green and yellow, representing the main research directions: the surge in telemedicine within urology driven by the COVID-19 pandemic, the application of telemedicine in dialysis, the importance of mobile application and technology for telemedicine development, the focus on urological care of telemedicine and the effectiveness evaluation of telemedicine on managing kidney diseases. The term "randomized controlled trial" displayed high frequency in 2019, suggesting high-quality investigation on the clinical effect of telemedicine. Besides, the occurrence of the term "virtual reality" spanned from 2004 to 2021, providing a potential and persistent development direction for telemedicine in urology. To sum up, we listed three hotspots for medical professionals as follows.

Effectiveness evaluation of telemonitoring in non-tumorous disease management

Conventional telemonitoring narrowly refers to patients sending testing results or images to doctors on their phones. In contrast, novel telemonitoring emphasizes using apps and machine learning models to collect dynamic data and monitor health status in real time. The data can then be transmitted to patients themselves, family members and caregivers via communication tools for timely intervention, which is of great benefit in addressing disparities for individuals living in remote locations, as well as those facing mobility constraints. Overall, this method goes beyond patient–doctor communication and empowers patients, families, as well as communities to actively participate in healthcare management themselves,[85] revolutionizing the application scenarios of telemonitoring.

Telemonitoring has emerged as a hotspot in the management of chronic and secondary kidney diseases, such as DKD and hypertensive nephropathy.[61,64,86] It tracks vital signs, medication adherence and symptoms, allowing for personalized and timely intervention. However, some studies proposed less ideal results with the advancement of clinical evaluation. For example, a clinical trial in 2024[87] found a non-significant promotion between the mobile phone-based intervention and no-monitor observation for physical activity in CKD patients. Developing prospective studies is the trend to investigate the effect of telemonitoring on treatment outcomes, cost-effectiveness and patient engagement.[88] Additionally, telemonitoring is tested and promoted in more non-tumorous diseases, such as male-specific health issues and urinary control disorders. The present results underscored its versatility and potential to address a broad range of non-tumorous conditions.[41,42] We anticipate the popularization and effectiveness of telemonitoring in urological diseases.

Cost–benefit analysis of teleconsultation after the COVID-19 pandemic

Beyond all doubts, the key driving force behind the proliferation of telemedicine lies in the COVID-19 pandemic, which greatly altered the way patients acquire medical help. Teleconsultation method has evolved from telephone calls to video conferencing and QR codes. To reduce the risk of COVID-19, a German urological office has built a system that allows patients to have video appointments with doctors in 2020.[89] So far, this concept of "virtual urologist" has confirmed its worth throughout the patient and doctor community.

As the world adapts to the new normal post-COVID-19, teleconsultation has become a frontier for providing continued healthcare. Despite potential drawbacks and limitations, studies have shown that teleconsultation has the potential to maintain equivalent efficiency while promising to reduce healthcare costs.[57,58,89] While cost–benefit analyses remain relatively scarce,[77] we anticipate more comprehensive evaluation studies on a larger scale. This endeavor necessitates collaborative efforts from hospitals, insurance companies and society. Additionally, given that costs are intricately linked to the software utilized, technology companies must also contribute. The ultimate goal is to ensure that the expenses incurred online are lower than the combined costs of travel and time.

Exploration of telesurgery technologies

Table 5 shows that the first two citation burst references were related to robot-assisted laparoscopic prostatectomy, which was the foundation of telesurgery. Actually, the term "telesurgery" performed mediocre in this bibliometric analysis with a rank of 28 in the top 30 author keywords (Table 6) and a 6-year research trend from 2008 to 2014 (Figure 9(B)). However, we supported that telesurgery represents a frontier in medical technology that promises to revolutionize surgical practice after comprehensive consideration of the development of network technique and the application of robotic-assisted surgical systems in urologic surgeries especially in prostate cancer. Despite the current limitations posed by high costs and technological barriers, the potential benefits of telesurgery are immense, which requires significant upfront investment from governments, as well as innovative exploration of pioneer efforts. The ability to perform complex surgeries remotely can bridge the gap between regions with abundant surgical expertise and those lacking sufficient resources. Further research and development of surgical robots, particularly in terms of precision, dexterity and adaptability, are essential for realizing the full potential of telesurgery.

During a procedure with the robotic-assisted surgical system, the surgeon's hand movements are translated into precise movements of the robotic instruments. To date, the most used robotic procedures in urology are prostatectomy, partial and radical nephrectomy, ureteroplasty, cystectomy and retroperitoneal lymph node dissection (RPLND).[90] Among them, prostatectomy for localized prostate cancer attracted the most attention mainly because of its high heterogeneity and serious implications on life quality. Thus, it also acted as a pioneer in the study of urological telesurgery.

Table 7 provided a summarization of the robotic-assisted surgical systems used in telesurgery in humans. The earliest clinical practice was in 2001 when Bauer et al. described a percutaneous renal surgery, in which the surgeon was located in Baltimore, while the patient was more than 7,000 km away in Rome using a plain old telephone system (POTS) line.[91] In the same year, the first trans-Atlantic robotic-assisted laparoscopic cholecystectomy, also known as the "Lindberg Operation",[92] symbolized the opening of modern telesurgery studies. Numerous remote surgical systems were invented over the years.[93–96] From 2019, several studies on robot systems using 5G networks were carried out,[97–100] marking a revolution in telesurgery. The wide application of 5G networks in the clinical area and the development of 5G+ networks in recent years remarkably shortened the time delay, resulting in more precision. The above successful surgeries further verified the feasibility and safety of telesurgery, also emphasizing the benefit of minimal injury and long-distance convenience compared to open surgery and traditional robot surgery. For future studies, interdisciplinary cooperation combining technological improvement and surgical innovation foresees a promising future.

Notably, although the da Vinci surgical system is widely used in many routine surgical procedures, it is not put into practice for telesurgery in humans, but only conducted experiments in porcine models.[101,102] Thus, we look forward to the clinical application of telesurgery on humans in the future.

Future study direction

To address the gaps and limitations in the current evidence base regarding telemedicine in urology, future research should focus on more detailed and actionable aspects. For example, studies could explore the effectiveness of specific telemedicine interventions in managing post-operative care for urological patients, comparing outcomes with traditional in-person care. Highlighting priority research areas, such as investigating access to telehealth care, patient satisfaction, treatment adherence and clinical outcomes, can enhance the clinical integration and real-world impact of telemedicine in urology. Intriguingly, with the current rapid development of artificial intelligence (AI), utilizing AI for personalizing telemonitoring to remarkably reduce doctors' involvement and improve productivity is considered to be a potential topic for future research.

Meanwhile, methodological improvements are essential to strengthen the quality of future research. Existing evidence for the use of telehealth interventions in urological diseases is of low quality due to methodological limitations and heterogeneity of intervention types. Researchers could consider employing more rigorous study designs, such as randomized controlled trials, to assess the efficacy of telemedicine interventions. Furthermore, building up a specialized data set to gain meaningful assessment and selecting appropriate outcome measures can provide valuable insights into the effectiveness of telemedicine in improving patient outcomes.

Additionally, previous papers have comprehensively discussed the intricacies of telemedicine on reimbursement rates definition, patients' privacy protection and accessibility and affordability insurance of telemedicine approaches.[62,77,86,103]

Table 7. Brief summarization of clinical practice of robotically assisted surgical systems used in telesurgery in humans.

Robot system	Year	Surgery type	Location	Approximate distance	Mean total time delay	Circuit
PAKY (percutaneous access of the kidney) robot[1]	2001	Percutaneous renal surgery	Baltimore, the United States to Rome, Italy	7000 km	NA	Plain old telephone system (POTS) line
ZEUS (Computer Motion, California)[2]	2001	Laparoscopic cholecystectomy for a 68-year-old female	New York, the United States to Strasbourg, France	7000 km	155 ms	A high-speed terrestrial optical-fiber network
Zeus TS microjoint system (Computer Motion, Inc., Santa Barbara, CA)[3,4]	2003	13 laparoscopic Nissen fundoplications Three laparoscopic right hemicolectomies One laparoscopic anterior resection Three laparoscopic sigmoid resections Two laparoscopic hernia repairs	St Joseph's Hospital to North Bay General Hospital (both in Hamilton, Canada)	400 km	135 ms to 150 ms	Internet Protocol-virtual private network at a bandwidth of 15 Mbps
CAS-BH5 frameless robotic system[5]	2005	Ten stereotactic neurosurgeries	Beijing to Yan 'an (both in China)	1300 km	NA	A digital data network
CorPath GRX robotic system (Corindus Robotics, Waltham, MA, USA)[6]	2018	Five tele-robotic-assisted percutaneous coronary artery interventions	the Apex Heart Institute in Ahmedabad to Akshardham, Gandhinagar (both in India)	32 km	53 ms	NA
TiRobot system[7]	2019	Four thoracolumbar fractures, six lumbar spondylolisthesis, two lumbar stenosis	Beijing Jishuitan Hospital to five hospitals in five different cities (all in China)	1300 km	28 ms	5G networks
Tumai Surgical Robot System (Shanghai, China)[8]	2022	Two laparoscopic surgeries in spermatic vein ligation	Nanjing to Xinjiang (both in China)	3800 km	130 ms	5G networks
MicroHand endoscopic surgical robot system (China)[9]	2022	Laparoscopic radical cystectomy in a 71-year-old man	Qingdao to Anshun (both in China)	2200 km	254 ms	5G networks
MP1000 surgical robotic system (Shenzhen Edge Medical Company, Shenzen, China)[10]	2023	Six urological telesurgeries involving four urological organs and five different operation types	Beijing to Sanya (both in China)	3000 km	48.37 ms to 52.20 ms	5G networks

The lower quality of patient–clinician relationships and overtreatment due to false judgment and unclarified laws related to the responsibility of telemedicine also threaten the spread of telemedicine. Therefore, corresponding laws and regulations regarding information safety and legal responsibility should be enacted as soon as possible, and relevant paradigms and protocols should be strengthened.

By incorporating these suggestions into future research endeavors, we can advance the understanding and implementation of telemedicine in urology, ultimately improving patient care and outcomes in this specialized medical field.

Limitations

Inevitably, there are some limitations in this study. First, to ensure high-quality bibliometric analysis, the data are only from the WoSCC database. Relevant data from other databases have been ignored. Second, we only included studies published in English, meaning that some linguistic bias has been introduced. Finally, due to the restriction of the data analysis software, some data may not receive enough attention. For example, in the author co-citation analysis, VOSviewer included only the first author of a cited document, which may omit some valuable authors.

Conclusion

The research of telemedicine in urology has been significantly boosted during the COVID-19 pandemic and continued unabated up to now due to its easier medical care access, better patient convenience and greater potential for healthcare cost reduction. Current research hotspots mainly focus on the three dimensions: (i) effectiveness evaluation of telemonitoring, (ii) cost–benefit analysis of teleconsultation and (iii) exploration of telesurgery. Looking forward to an active settlement on barriers, such as patient acceptance, ethical considerations, legal challenges and financial issues compared with the traditional healthcare systems, we recommend more high-quality clinical trials related to telemedicine in urology and support its great potential.

Contributorship: Na Zeng and Mei-Cheng Liu analyzed the data, wrote the manuscript and drew the figures. Qi-Dong Xia and Shao-Gang Wang designed the study. Xing-Yu Zhong contributed to the critical revision of the manuscript. All authors read and approved the final manuscript.

Declaration of Conflicting Interests: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

ORCID iD: Mei-Cheng Liu https://orcid.org/0009-0004-3965-1326

Supplemental material: Supplemental material for this article is available online.

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