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REVIEW ARTICLES

Technological development in telemedicine: bibliometric analysis, research gaps, and literature trends

Desenvolvimento tecnológico na telemedicina: análise bibliométrica, lacunas de pesquisa e tendências na literatura

Desarrollo tecnológico en telemedicina: análisis bibliométrico, lagunas en la investigación y tendencias en la literatura

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ABSTRACT

The aim of this article was to analyze the literature on technological development in telemedicine through bibliometrics, by identifying the state of the art, research gaps, and trends in the literature. The analysis covers a total of 67 articles related to the field of study, published between 2010-2020 in the Springer Link, Science Direct, Wiley Online Library, Web of Science, and Scopus databases. The data was processed using the software StArt, Excel, IBM SPSS Statistics, and Iramuteq. The results presented bibliometric analysis of the articles, classified into the areas of Management (52.2%), IT (25.4%), and Medicine (22.4%), along with a Table of 34 suggestions for future research. Literature trends encompassed six study clusters (health, study, service, technology, patient, and telemedicine), which further subdivided into nine research themes (digital platform, telemedicine service management, telemedicine service operation, end-user perception, business opportunities, healthcare professional perception, covid-19, regulation, and robotics). An observed outcome was a significant increase in the number of publications in the area due to covid-19.

Keywords: Telemedicine; Telehealth; e-Health; m-Health; Literature review; Covid-19.

RESUMO

O objetivo deste artigo foi analisar a literatura acerca do desenvolvimento tecnológico na telemedicina, por meio da bibliometria, ao identificar o estado da arte, lacunas de pesquisa e tendências na literatura. Analisou-se 67 artigos relacionados ao campo de estudo, publicados entre 2010-2020 nas bases de dados Springer Link, Science Direct, Wiley Online Library, Web of Science e Scopus. O tratamento dos dados se deu por meio dos softwares StArt, Excel, IBM SPSS Statistics e Iramuteq. Os resultados apresentaram a análise bibliométrica dos artigos, classificados nas áreas de Gestão (52,2%), TI (25,4%) e Medicina (22,4%), e uma tabela com 34 sugestões para pesquisas futuras. As tendências da literatura envolveram seis classes de estudo (saúde, estudo, serviço, tecnologia, paciente e telemedicina), que se subdividiram em nove temas de pesquisa (plataforma digital, gestão do serviço de telemedicina, operação do serviço de telemedicina, percepção do usuário final, oportunidades de negócios, percepção de profissionais de saúde, covid-19, regulamentação e robótica). Observou-se aumento significativo no número de publicações na área devido à covid-19.

Palavras-chave: Telemedicina; Telessaúde; e-Saúde; m-Saúde; Revisão da literatura; Covid-19.

RESUMEN

El objetivo de este artículo fue analizar la literatura sobre el desarrollo tecnológico en la telemedicina mediante bibliometría, identificando el estado del arte, las lagunas de investigación y las tendencias en la literatura. Se analizaron un total de 67 artículos relacionados con el campo de estudio, publicados entre 2010-2020 en las bases de datos de Springer Link, Science Direct, Wiley Online Library, Web of Science y Scopus. Los datos fueron procesados utilizando los programas StArt, Excel, IBM SPSS Statistics e Iramuteq. Los resultados presentaron un análisis bibliométrico de los artículos, clasificados en las áreas de Gestión (52,2%), TI (25,4%) y Medicina (22,4%), junto con una tabla de 34 sugerencias para futuras investigaciones. Las tendencias en la literatura abarcaron seis clases de estudio (salud, estudio, servicio, tecnología, paciente y telemedicina), que se subdividieron en nueve temas de investigación (plataforma digital, gestión del servicio de telemedicina, operación del servicio de telemedicina, percepción del usuario final, oportunidades de negocio, percepción de los profesionales de la salud, covid-19, regulación y robótica). Un resultado observado fue un aumento significativo en el número de publicaciones en el área debido al covid-19.

Palabras clave: Telemedicina; telesalud; e-salud; m-Salud; Revisión de literatura; Covid-19.

ARTICLE INFORMATION

Author's contributions:
Study conception and design: Erick de Freitas Moura; Ieda Kanashiro Makiya; Maurilio Barbosa de Oliveira da Silva.
Data acquisition, analysis, or interpretation: Erick de Freitas Moura; Ieda Kanashiro Makiya; Maurilio Barbosa de Oliveira da Silva.
Manuscript drafting: Erick de Freitas Moura.
Critical review of intellectual content: Erick de Freitas Moura; Ieda Kanashiro Makiya; Maurilio Barbosa de Oliveira da Silva.

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INTRODUCTION

Telemedicine can be defined in three domains: functionality, application, and technology. The domain of functionality refers to the uses of this technology for managing patients, such as consultation, diagnosis, monitoring, and guidance. Consultation refers to communication between healthcare providers, such as between a specialist and a primary care provider. Diagnosis concerns the process of storing and forwarding exams, in which the latter is sent to a specialist for asynchronous evaluation. Monitoring involves using equipment to monitor a patient's physiological state and guidance is a mode where an expert guides another healthcare provider's work in real time, such as an operation (Bashshur *et al.*, 2011).

The domain of application is subdivided into medical specialty and/or disease, place of care, and treatment modality. The medical specialty led to the use of various tele terms, such as teledermatology and teleallergy, depending on the provider's specialty and/or the disease being treated. The place of care covers the location where patients are assisted remotely, and the modality alludes to the types of treatment, such as rehabilitation and physical therapy, also provided remotely (Bashshur *et al.*, 2011). The domain of technology, in turn, refers to the different electronic media through which telemedicine can be provided, due to the multiplicity of individual suppliers or startups (Waller; Stotler, 2018).

The various functionalities, applications, and technologies involved in the provision of telemedicine services, as well as the possibilities for health care in places where it is difficult to hire and maintain health professionals, such as in remote locations (Bagayoko *et al.*, 2014; Pagalday-Olivares *et al.*, 2017) and rural areas (Currie; Philip; Roberts, 2015; Khan *et al.*, 2015), indicate the importance of telemedicine for overcoming physical obstacles to accessing health care. Furthermore, the pandemic caused by covid-19 reinforces the need to reduce professional knowledge gaps in geographically distant areas (Eisenstein *et al.*, 2020) and the ways in which health service providers care for their patients (Grimes *et al.*, 2020). To alleviate the problems mentioned, telemedicine stands out as an effective means by which patients can be diagnosed, medicated, and monitored, without physical contact.

Telemedicine is an emerging field of study whose importance has been reinforced by covid-19 (Kim; Choi; Han, 2020). Subsequently, quantifying the literature, through a bibliometric study, to observe the status of this field of study, as well as identifying the research gaps and trends is essential. According to Huang *et al.* (2016), bibliometrics is a scientific discipline that makes use of statistical tools to quantify and analyze the literature in a given area of knowledge. Thus, the research questions that guided this study are: What is the state of the art of technological development in telemedicine? What are its scientific gaps and literature trends?

Thus, this article aims to analyze the literature on technological development in telemedicine using bibliometrics, by identifying the state of the art, scientific gaps, and literature trends. For this, articles were collected from five databases: Springer Link, Science Direct, Wiley Online Library, Web of Science, and Scopus, which were analyzed using bibliometrics.

The central aim of this study is to characterize the technological development in telemedicine and highlight the methodological aspects used in the literature, in addition to presenting a framework based on the scientific gaps extracted from the analyzed texts, which will serve as a guide for understanding the field of study, as well as directing future studies to little explored or unexplored areas.

RESEARCH METHODS

The methodological steps of this bibliometric research are shown in Figure 1 and were based on research by da Silva *et al.* (2018) and de Araújo, Alencar and de Miranda Mota (2017). Articles searched for and collected had to meet the following criteria: published between 2010 and 2020, be an article or review article, and be written in the English language. The structured keywords were "technology development"

AND telemedicine OR "technology development" AND telehealth OR "technology development" AND eHealth, searched for in the title, abstract, and keywords. The databases used (Figure 1) were chosen as they allow the export of metadata for analysis, as well as being the main databases used in bibliometric research.

Articles and review articles, published in indexed journals, were chosen because they are peer-reviewed and therefore the most reliable for literature review purposes (Garza-Reyes, 2016). Thus, articles from conferences, books, book chapters, notes, letters, and editorials were not even considered in the search filters for structured keywords. Non-academic databases and gray literature were not searched because of their unreliability, and English was adopted since it is the scientific language (da Silva *et al.*, 2018).

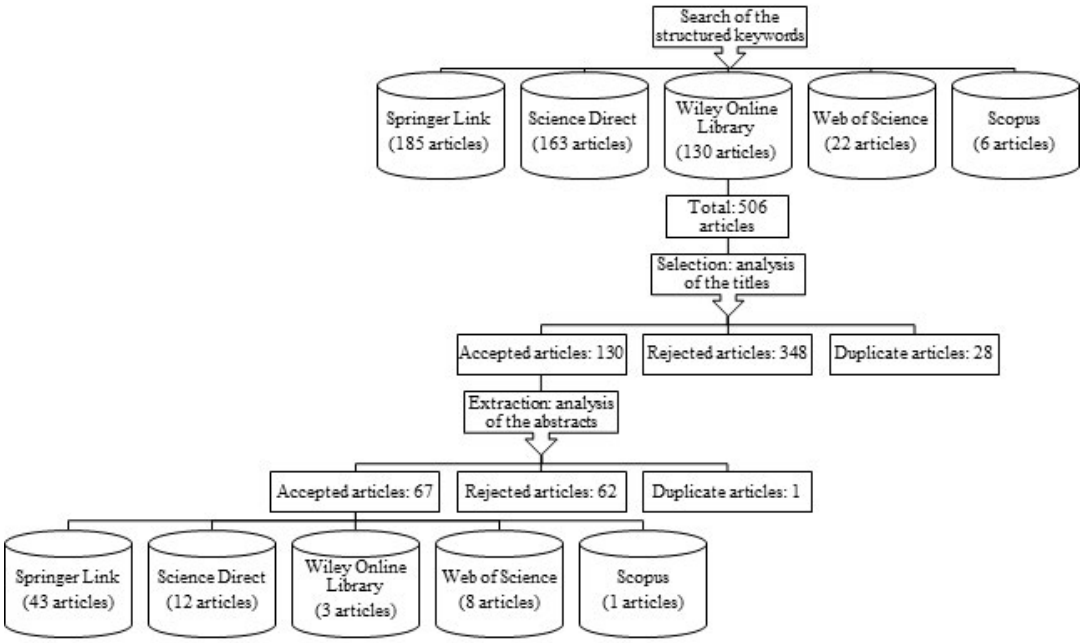

Figure 1 – Research design
Source: prepared by the authors.

The metadata extracted from the surveyed databases were exported to BibTex format, except for those from the Springer Link database, which only exports to CSV format. In the latter case, the DOI number exported to CSV format was used, the articles and their metadata were retrieved by Zotero software, and then exported to BibTex format. The BibTex format was chosen because it is compatible with the StArt bibliometric analysis software.

The article selection and extraction steps (Figure 1) were performed using StArt software, and the 67 accepted articles, components of this bibliometric review, were exported to CSV format to be treated in Excel. The Excel table contains the labels shown in Figure 2. The cross-hatched labels in green refer to data extracted from the article itself, as they originally appear, exported from the StArt software. The cross-hatched labels in blue were taken from Google Scholar. Those in pink are analysis categories defined by the authors – three research area options were listed (Management, Medicine, and IT). Whereas, the research themes emerged from the content analysis of the articles. Finally, the yellow labels were determined by the authors based on their reading of the articles.

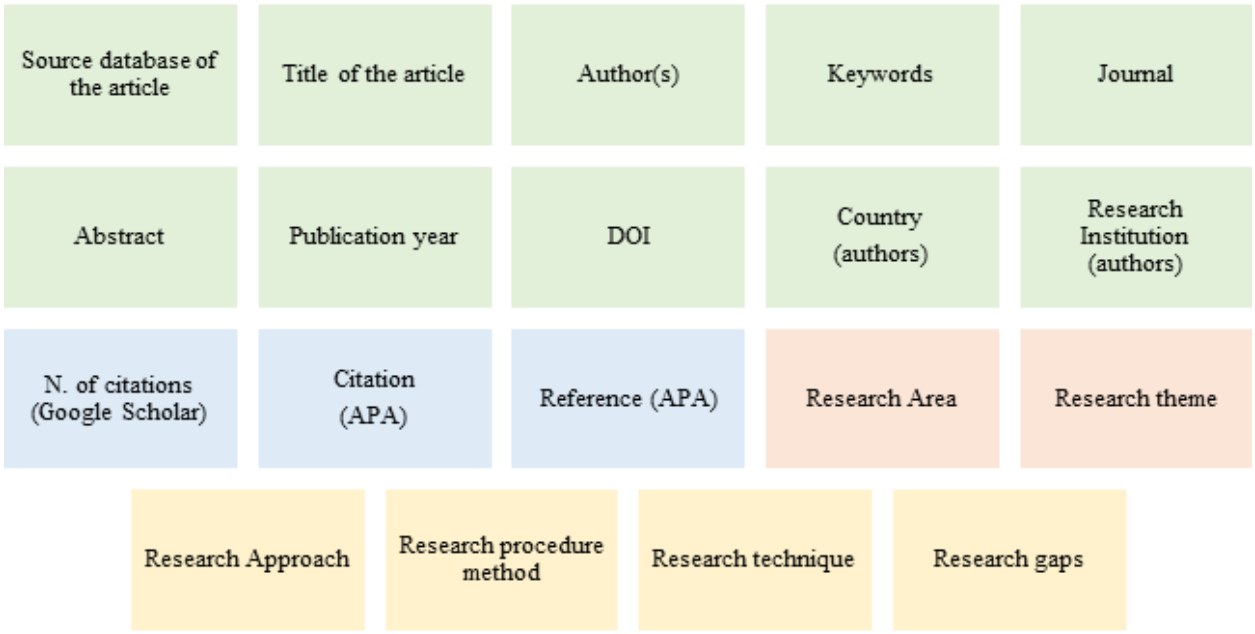

Figure 2 – Data sheet labels
Source: prepared by the authors.

The labels "research approach," "research procedure method," and "research technique" (Figure 2) analyzed in the study were derived from the definitions of the terms created by Lakatos and Marconi (2017a, 2017b, 2018), as shown in Table 1.

Table 1 – Criteria for identifying the research methodology of the analyzed articles

Research approach	Research procedure method		Research technique	
Qualitative	History	Phenomena in historical conditions	Indirect documentation	Documentary research
	Comparative	Comparison of hard data	Bibliographic research	Search in available literature
Quantitative	Monographic	Case study and multiple case study	Direct documentation	Field research, experimental research, action research, and laboratory research
	Statistical	Reduction of phenomena to quantitative terms and statistical manipulation		
	Typological	Comparison of complex social phenomena	Intensive direct observation	Observation and interview
	Functionalist	Study of society from the point of view of its functions		
Mixed	Structuralist	Representation of reality by models	Extensive direct observation	Questionnaire, form, and opinion/attitude measures
	Ethnographic	Description of ethnicities and cultures		

Source: prepared by the authors, based on Lakatos and Marconi (2017a, 2017b, 2018).

The analysis of the labels shown in Figure 2 was performed using IBM SPSS Statistics and Excel, by frequency and simple count analysis, except for the "abstract," for which the content analysis software Iramuteq was used, and the "research gaps," which were identified in the analyzed articles and described. Iramuteq processes qualitative data through two primary text segment analysis techniques (lexical relationships), Descending Hierarchical Classification (DHC), from which categories and subcategories emerge

as units of analysis, and Similitude Analysis, which reveals the most significant words in the textual corpus and how they connect, thus serving as a synthesis of DHC (Camargo; Justo, 2018; Souza *et al.*, 2018).

Similitude Analysis, used in the analysis of "abstracts", is a technique rooted in Graph Theory, with the aim of highlighting proximity and relationships among a set of elements in the form of maximum trees, by reducing the number of links to generate a connected and cycle-free graph. This technique was integrated into the Iramuteq software to characterize lexical classes, identify the various themes they encompass, and graphically represent the structure of a textual corpus (Marchand, Ratinaud, 2012). Therefore, Iramuteq processes qualitative data for analysis by researchers (Camargo; Justo, 2021).

BIBLIOMETRIC ANALYSIS

Bibliometric studies help to identify research trends (Jensen; Rouquier; Croissant, 2009) quantitatively, mainly due to the increasing availability of tools to analyze large data sets (Ellegaard; Wallin, 2015). The data collected, as shown in Figures 1 and 2, allowed analyses on the evolution of publications in the past ten years, frequent research areas and themes, keywords, articles, authors, journals, countries, and research institutions most cited, in addition to the methodological procedures most used, research gaps, and literature trends.

Analysis of publications: evolution in the past ten years, frequent research areas, and most cited keywords and articles

There was a significant increase in interest among researchers about technological development in telemedicine in 2020 (Figure 3), mainly due to the covid-19 pandemic, which reinforced the need for teleservice (Eisenstein *et al.*, 2020; Grimes *et al.* 2020; Monaghesh; Hajizadeh, 2020), for the management of telemedicine services (Allaert *et al.*, 2020; Harst *et al.*, 2019; Kho, Gillespie; Martin-Khan, 2020; Kim; Choi; Han, 2020; Ncube; Mars; Scott, 2020), and the ways of operating them (Castaneda; Ellimoottil, 2020; George; Cross, 2020; Huang *et al.*, 2020; Koehler *et al.*, 2020; Wahba *et al.*, 2020).

We also highlight the articles by Anwar and Prasad (2018) and Dananjayan and Raj (2020), which deal with the transformation of health made possible by 5G technology, and by Boonstra and Van Offenbeek (2010), the oldest article published in the defined search criteria and the ninth most cited (Table 3).

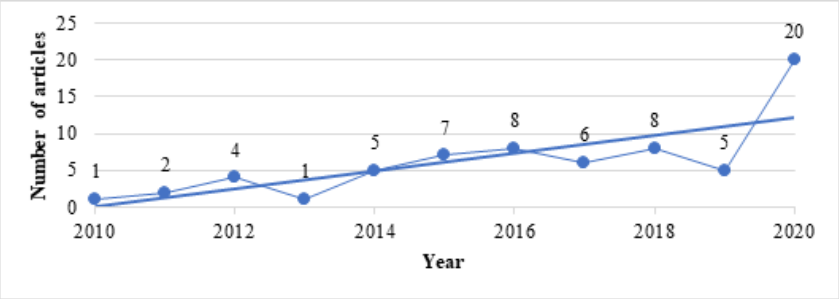

Figure 3 – Evolution of publications on technological development in telemedicine in the past ten years
Source: prepared by the authors in Excel.

The research areas were standardized in Management, IT, and Medicine, since telemedicine is a frontier area between these fields of study: 52.2% of the articles analyzed are in Management, and the areas of IT and Medicine correspond to 25.4% and 22.4%, respectively (Figure 4). The predominance of the Management area is noticeable, which indicates the authors' concern with organizational forms and challenges for implementing telemedicine services.

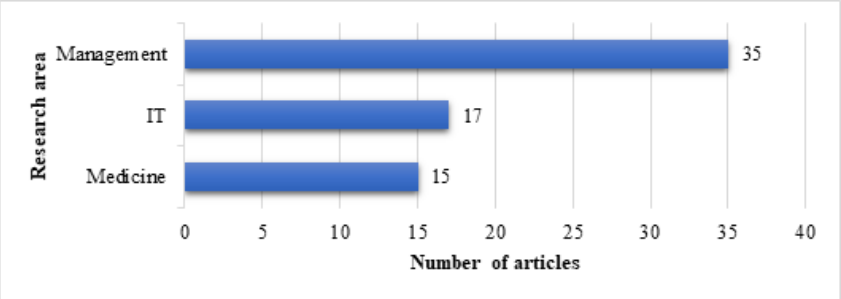

Figure 4 – Research areas
Source: prepared by the authors in Excel.

The keywords of the articles were analyzed to identify the topics most frequently addressed by the authors, and which characterize their research. Some of the selected articles have no keywords. Commonly an article has more than one keyword, usually up to five. Therefore, considering the idiosyncrasies of this study, different terms that have the same meaning or a similar meaning were standardized to the same keyword (Table 2).

Table 2 – Standardized keywords and authors' original keywords

Standardized keywords	Authors' original keywords
Telemedicine	Telemedicine; telemedicine security; telemedicine credentialing.
e-Health	e-Health; eHealth; survey on eHealth; eHealth technologies; eHealth literacy; eHealth ecosystem; eHealth services.
Telehealth	Telehealth; telehealth services; telehealth videoconferencing; home telehealth services;
Technology	Technology; technology development; technology adoption; gerontechnology; technology transfer; assistive technology; health technology; technology acceptance; health information technology; digital health technology; medical technology; technology acceptance model; health care information technology; technology selection; technology acceptance prediction; health technology forecasting; health technology assessment; technology innovation; technology implementation; technology ventures; key technology challenges; technology development challenges; promising technology; disruptive technology; wearable technology; technology acceptance modeling; technology design; patience technology interaction; technology roadmap.
Internet of Things	Internet of Things; Medical Internet of Things; Internet of Medical Things; Internet of Multimedia Things.
m-Health	m-Health; mHealth; mobile health; mobile health application; mobile based health communications; mobile health technology.
Telecare	Telecare; telecare security; telemonitoring; telerehabilitation; teledermatology; teleconsultation; teleactivities; teleophthalmology; telepsychiatry; telestroke.
Policy	Policy; Health policy; policy analysis; law and policy; public policy; space policy;
Healthcare	Healthcare; healthcare services; healthcare systems; healthcare domain; healthcare Industry 4.0.
Mental health	Mental health; mental healthcare.
Developing countries	Developing countries; low income and middle-income countries.
Innovation	Innovation; Innovation management; innovation ecosystem; digital innovation; health innovation; technology innovation; social innovation; innovation diffusion; medical innovation; hybrid innovation; innovation management routines; radical innovation.
Literature review	Literature review; systematic review; scoping review; systematic literature review; state-of-the-art review.
Covid-19	Covid-19; coronavirus.
Africa	Africa; South Africa; Sub-Saharan Africa.
Robotics	Robotics; care robotics; robots.
Sustainability	Sustainability; sustainable development; sustainability transitions.

Source: prepared by the authors.

The twenty keywords most used by the authors to characterize their studies are presented in Figure 5. Except for the keywords technology, telemedicine, telehealth, and e-Health, which were part of the search filter, there is a high frequency of the terms m-Health, often used to refer to the use of smartphones to provide the service of telemedicine, followed by telecare, which refers to remote medical treatment/monitoring. There is also a high frequency of studies characterized as literature reviews, as well as addressing the concept of Internet of Things.

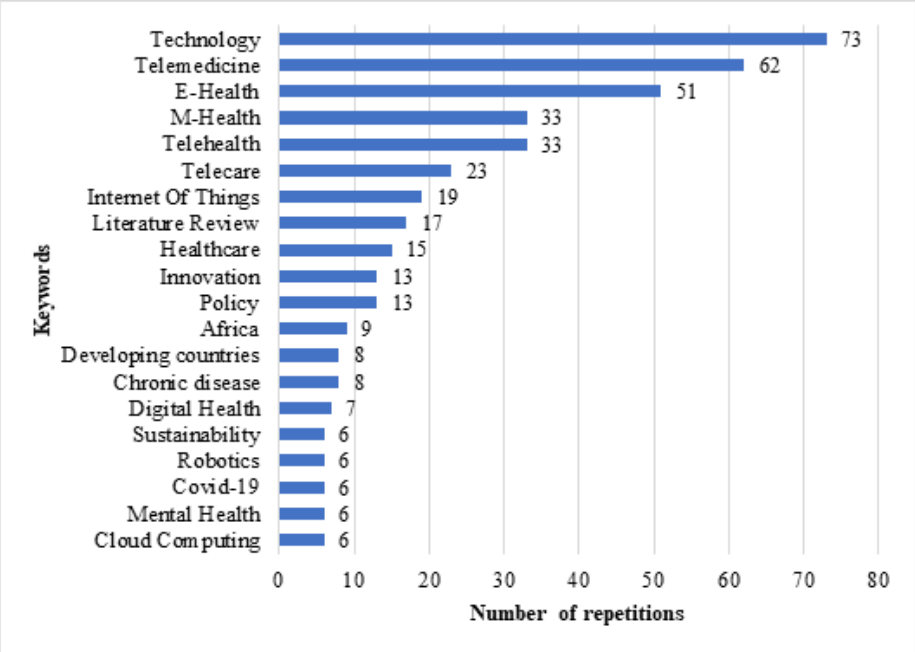

Figure 5 – Twenty most frequent keywords
Source: prepared by the authors in Excel.

With the technological advancements in telehealth, an increase in users embracing its usage is expected, driven by health education processes and telehealth promotion. Business opportunities lie in innovation and service integration, while obstacles, on the other hand, include stringent healthcare regulations (Tsai, 2020). Tsai (2020) developed a combination of qualitative and quantitative methods to explore estimated future innovation diffusion.

Figure 6 presents, in word cloud format, all 150 keywords of the articles, whose highlights are still the terms technology, telemedicine, e-Health, m-Health, telehealth, telecare, and Internet of Things; notwithstanding, there is also an emphasis on the terms innovation, ICT, robotics, 5G, cloud computing, policy, ethics, education, covid-19, business model, rural health, Africa, developing countries, female, sustainability, and aged, which characterize what is being researched when dealing with technological innovation in telemedicine.

We emphasize that the terms rural health, developing countries, and Africa, together, indicate the use of telemedicine as a means of overcoming the lack of doctors in poor or remote areas, as in the studies by Currie, Philip and Roberts (2015), Khan *et al.* (2015), Pagalday-Olivares *et al.* (2017), Lee *et al.* (2018), Walters, Scott and Mars (2018), Gebre-Mariam and Bygstad (2019), Kiberu, Scott and Mars (2019), Nikolaidis, Efthymiadis and Angelidis (2019) and Wahba *et al.* (2020).

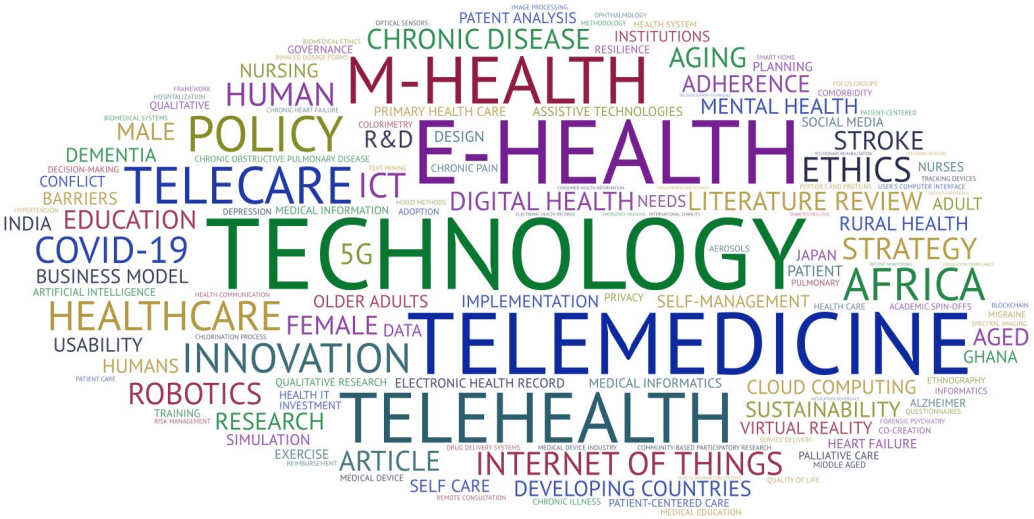

Figure 6 – Word cloud of all keywords
Source: prepared by the authors in Word Cloud.

The ten most cited articles were ranked by the number of citations of the article in Google Scholar, as this tool considers not only citations in specific databases, but global ones. Furthermore, the table includes the title of the article, its authors, the journal where it was published, and the Scimago Journal Rank (SJR), which measures the impact factor of journals by the number of citations and relevance of the journal (Falagas *et al.*, 2008).

Table 3 – Most cited articles

(continued)

N.	Title	Author(s)	Journal (ISSN)	SJR	N. of citations
1	A Systematic Review of Healthcare Applications for Smartphones	Mosa, Yoo and Sheets (2012)	BMC Medical Informatics and Decision Making (1472-6947)	0.908	1.100
2	Analyzing older users' home telehealth services acceptance behavior – applying an Extended UTAUT model	Cimperman, Brenčič and Trkman (2016)	International Journal of Medical Informatics (1386-5056)	0.954	156
3	The determinants of home healthcare robots adoption: An empirical investigation	Alaiad and Zhou (2014)	International Journal of Medical Informatics (1386-5056)	0.954	141
4	How do business model and health technology design influence each other? Insights from a longitudinal case study of three academic spin-offs	Lehoux *et al.* (2014)	Research Policy (0048-7333)	3.246	132
5	Telemedicine in pre-hospital care: a review of telemedicine applications in the pre-hospital environment	Amadi-Obi *et al.* (2014)	International Journal of Emergency Medicine (1865-1372)	0.477	90
6	Attitudes towards the use and acceptance of eHealth technologies: a case study of older adults living with chronic pain and implications for rural healthcare	Currie, Philip and Roberts (2015)	BMC Health Services Research (1472-6963)	0.995	88
7	Adherence and factors affecting satisfaction in long-term telerehabilitation for patients with chronic obstructive pulmonary disease: a mixed methods study	Hoaas *et al.* (2016)	BMC Medical Informatics and Decision Making (1472-6947)	0.908	68

(concluded)

8	Systematic Review of Real-time Remote Health Monitoring System in Triage and Priority-Based Sensor Technology: Taxonomy, Open Challenges, Motivation and Recommendations	Albahri *et al*. (2018)	Journal of Medical Systems (0148-5598)	0.686	66
9	Towards consistent modes of e-health implementation: structurational analysis of a telecare programme's limited success	Boonstra and Van Offenbeek (2010)	Information Systems Journal (1350-1917)	2.083	60
10	Bridging two translation gaps: A new informatics research agenda for telemonitoring of chronic disease	Hardisty *et al*. (2011)	International Journal of Medical Informatics (1386-5056)	0.954	58

Source: prepared by the authors.

The article "A Systematic Review of Healthcare Applications for Smartphones," by Mosa, Yoo and Sheets (2012), is the most influential article in the field of study, with 1,100 citations, having 944 citations more than the second most cited article in this field. The above article highlights the growing use of smartphones by health professionals for patient care and, through a literature review, classified smartphone-based health technologies according to their functionalities. A total of 83 applications were documented.

Analysis of authors with the most published articles

The authors who have published more articles on technological development in telemedicine are shown in Figure 7. Only authors with more than one article published in the field of study were considered. Authored and co-authored articles were recognized. Unlike da Silva *et al*. (2018), whose ten most cited authors had regular publications on Lean Six Sigma, in this research there are no traditional authors in the field of study. This is because it is new, on the frontier, and with publications emerging in 2020, as Figure 3 shows. However, two or more publications in the field of study indicate research interest. According to Figure 7, there were 29 authors who had two or more publications that met the aforementioned criteria.

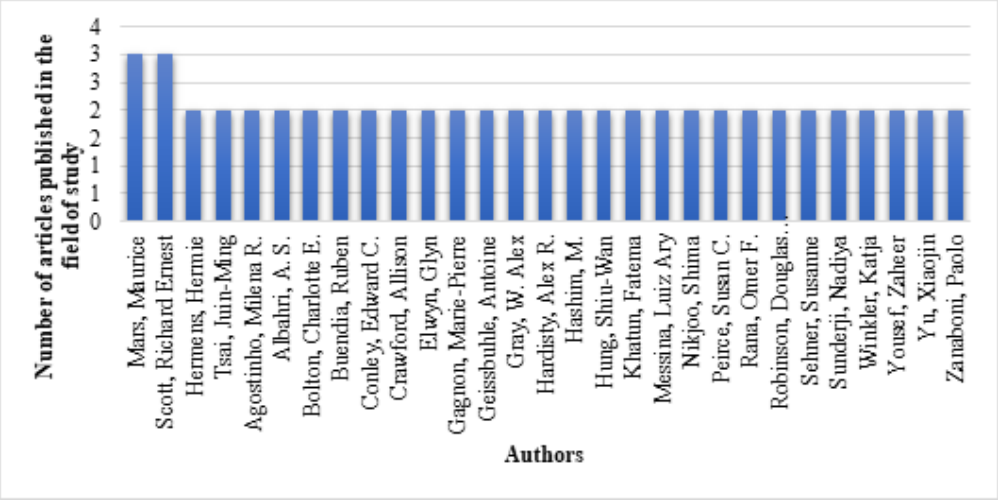

Figure 7 – Authors with more published articles
Source: prepared by the authors in Excel.

The 67 articles analyzed have 296 different authors, which generates an average of 4.4 authors per article. The two authors with the most published articles are Maurice Mars and Richard Ernest Scott, who have co-authored three articles (Kiberu; Scott; Mars, 2019; Ncube; Mars; Scott, 2020; Walters; Scott; Mars, 2018). Maurice Mars is Professor of Telehealth at the University of KwaZulu-Natal, South Africa, and has a total of 3,456 Google Scholar citations. His publications, even before 2010, are about telehealth.

Richard Ernest Scott is a professor at the University of KwaZulu-Natal, South Africa, and at the University of Calgary, Canada, and has no Google Scholar profile.

Review of journals

The journals chosen by the authors to publish their articles total 40; nevertheless, the journals described were those with two or more publications in the field of study. After applying this filter, 8 journals remained, ranked in Figure 8 and better explained in Table 4.

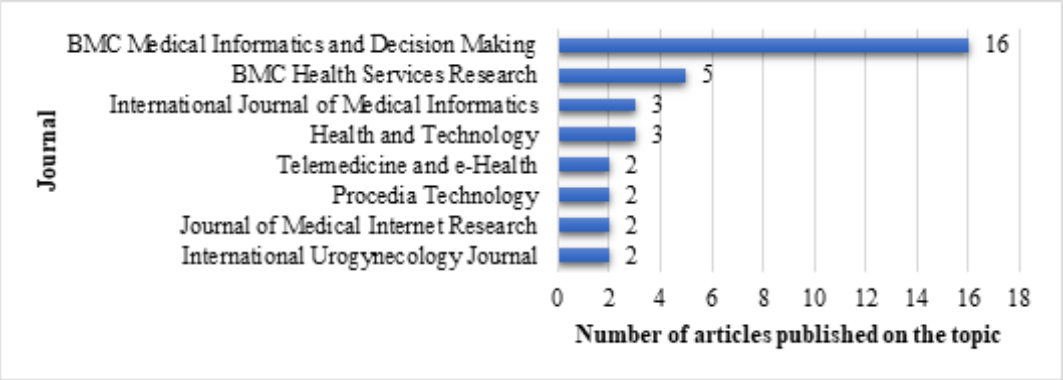

Figure 8 – Ranking of journals with the highest number of publications
Source: prepared by the authors in Excel.

The journal with the most published articles in the field of study is BMC Medical Informatics and Decision Making (16 articles), followed by BMC Health Services Research (5 articles), both from BioMed Central Ltd. The International Journal of Medical Informatics, by Elsevier Irland Ltd, and Health and Technology, by Springer Verlag, occupy the third place in the ranking with three articles each. The other four magazines tied for fourth place in the ranking, with two articles each.

Table 4 – Ranking of journals with the highest number of publications

N.	Journal (ISSN)	Publisher	SJR	N. of citations (Research)
1	BMC Medical Informatics and Decision Making (1472-6947)	BioMed Central Ltd.	0,908	16
2	BMC Health Services Research (1472-6963)	BioMed Central Ltd.	0,995	5
3	International Journal of Medical Informatics (1386-5056)	Elsevier Ireland Ltd	0,954	3
4	Health and Technology (2190-7188)	Springer Verlag	0,246	3
5	Telemedicine and e-Health (1530-5627)	Mary Ann Liebert Inc.	0,779	2
6	Procedia Technology (2212-0173)	Elsevier	-	2
7	Journal of Medical Internet Research (1438-8871)	Journal of Medical Internet Research	1,187	2
8	International Urogynecology Journal (1433-3023)	Springer London	0,959	2

Source: prepared by the authors.

The highest SJR impact factor of journals ranked by number of publications is that of the Journal of Medical Internet Research, 1.187 (Table 4); even so, this journal has an impact factor below the two journals Research Policy and, Information Systems Journal, which have a factor of 3.246 and 2.083 respectively, and in which two of

the ten most cited articles in this research were published (Table 3). The Procedia Technology journal, by Elsevier, has been discontinued, so it does not have an SJR factor indicated in Table 4.

Analysis of countries and research institutions by number of articles published

The 67 articles analyzed have authors linked to research institutions in 34 countries. As a research filter, in the preparation of Figure 9, a minimum of two published articles linked to research institutions in the country was considered. The United States of America leads the ranking of countries with the most articles published in this field of study, with ten articles linked to North American research institutions, followed by Canada and Norway with five; Netherlands and Taiwan with four; South Africa, Australia, China, South Korea, France, Iran, and the United Kingdom with three; and Germany, Brazil, Greece, and India with two.

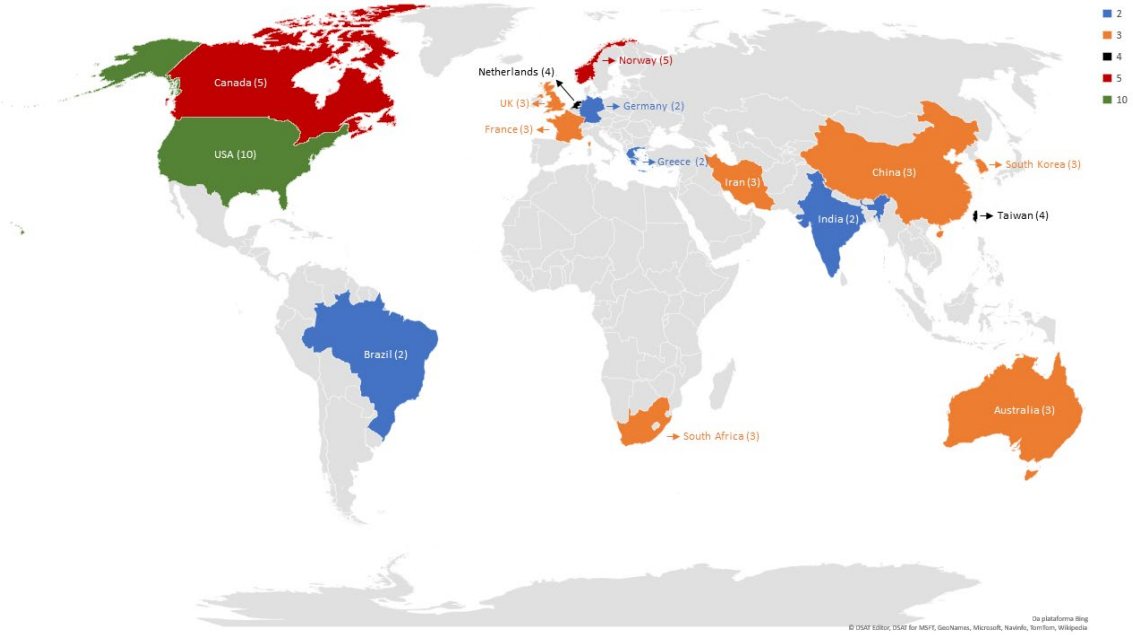

Figure 9 – Ranking of countries with the most published articles
Source: prepared by the authors in Excel.

In addition, 97 research institutions were listed in this study, and when considering the minimum frequency of two published articles linked to each institution, 11 universities met the criterion, as shown in Table 5.

Table 5 – Universities with more research in the field of study

University	Country
University of Toronto	Canada
University of Twente	Netherlands
University of Oslo	Norway
University of KwaZulu-Natal	South Africa
Seoul National University	South Korea
National Central University	Taiwan
National Chiayi University	Taiwan
National Taipei University	Taiwan
Cardiff University	UK
University of Nottingham	UK
University of Texas	USA

Source: prepared by the authors.

Shen, Wang and Yang (2020) discussed the possibilities of patenting opportunities in intelligent healthcare management and scientific advancements in home care systems. The latter, considered an opportunity for scientific advancements in telehealth, signifies a scenario of expanding research in the field.

Analysis of research methodology: approach, procedure method, and technique

In this section, we sought to highlight the methodological procedures adopted in research on technological development in telemedicine in the past ten years. These may indicate, on the one hand, trends in methodological procedures to be used and, on the other hand, possibilities to explore the theme by methods that are still used rarely or not used at all, thus increasing the explanatory potential of this field of study. In terms of their research approaches, 66% of articles refer to qualitative research, 21% to quantitative research, and 13% use both methods.

In most articles (41.8%), the procedure method was not explicit or was not identified by the authors. Nevertheless, of those remaining, there was a predominance of statistical (20.9%) and monographic, functionalist, and structuralist methods (the latter ones with 10.4% each). Only one article used the comparative procedure method, and three articles used the ethnographic method.

The bibliographic research technique was the most expressive in the studies, representing 32.9% of them, followed by extensive direct observation (21.5%), intensive direct observation (19%), indirect documentation (10.1%), and direct documentation (8.9%). It was not possible to identify the technique used in just 7.6% of the articles.

Research gaps in the literature

Only 34 of the 67 articles analyzed clearly pointed out directions for future studies on technological development in telemedicine. Table 6 addresses these scientific gaps. The gaps were presented when considering the idiosyncrasies of each study; however, it was possible to see some patterns of suggestions for future studies. Three articles indicated further study on the co-design of e-Health processes and technologies (Anwar; Prasad, 2018; Elwyn *et al.*, 2012; Eyles *et al.*, 2016). Another five articles suggested studies on the perception of end users regarding the use of telemedicine (Cimperman; Brenčič; Trkman, 2016; Hoaas *et al.*, 2016; Mougiakakou *et al.*, 2011; Sezgin; Yildirim, 2014; Tsai *et al.*, 2019).

The development of future studies on the institutional regulatory environment of telemedicine was suggested by Troshani, Goldberg and Wickramasinghe (2012) and George and Cross (2020). Furthermore, despite simple differences in the wording of their propositions, Khan *et al.* (2015) and Balakrishnan *et al.* (2016) suggested future research on technological development in health in emerging countries.

Table 6 – Research gaps in the literature

(continued)

Article	Journal	SJR	Author(s)	Research gaps
Assessing core, e-learning, clinical and technology readiness to integrate telemedicine at public health facilities in Uganda: a health facility – based survey	BMC Health Services Research	0,995	Kiberu, Scott and Mars (2019)	Barriers to implementing telemedicine
Co-design of mHealth Delivered Interventions: A Systematic Review to Assess Key Methods and Processes	Current Nutrition Reports	0,834	Eyles et al. (2016)	Co-design of eHealth processes and technologies
Detecting deterioration in patients with chronic disease using telemonitoring: navigating the `trough of disillusionment'	Journal of Evaluation in Clinical Practice	0,588	Elwyn et al. (2012)	Co-design of eHealth processes and technologies
Framework for Future Telemedicine Planning and Infrastructure using 5G Technology	Wireless Personal Communications	0,291	Anwar and Prasad (2018)	Co-design of eHealth processes and technologies
Defining competencies for the practice of telepsychiatry through an assessment of resident learning needs	BMC Medical Education	0,831	Crawford et al. (2016)	Skills development for telemedicine
Characterization of Patient Interest in Provider-Based Consumer Health Information Technology: Survey Study	Journal of Medical Internet Research	1,187	Featherall (2018)	Development of predictive models for eHealth systems
A regulatory framework for pervasive e-health: A case study	Health Policy and Technology	0,314	Troshani, Goldberg and Wickramasinghe (2012)	Development of the institutional regulatory environment
Remote Monitoring and Telemedicine in IBD: Are We There Yet?	Current Gastroenterology Reports	1,113	George and Cross (2020)	Development of the institutional regulatory environment
Complementing a Clinical Trial with Human-Computer Interaction: Patients' User Experience With Telehealth	Journal of Medical Internet Research	1,187	Jalil et al. (2019)	Technological development complementary to telehealth
Continuum of Care Services for Maternal and Child Health using mobile technology – a health system strengthening strategy in low and middle income countries	BMC Medical Informatics and Decision Making	0,908	Balakrishnan et al. (2016)	Technological development in health for emerging countries
Experience of using mHealth to link village doctors with physicians: lessons from Chakaria, Bangladesh	BMC Medical Informatics and Decision Making	0,908	Khan et al. (2015)	Technological development in health for emerging countries as an alternative to the shortage of professionals
Bridging two translation gaps: A new informatics research agenda for telemonitoring of chronic disease	International Journal of Medical Informatics	0,954	Hardisty et al. (2011)	Development of services compatible with telemedicine platforms; Co-design of eHealth processes and technologies
Design and implementation of an m-health data model for improving health information access for reproductive and child health services in low resource settings using a participatory action research approach	BMC Medical Informatics and Decision Making	0,908	Thobias and Kiwanuka (2018)	Education in the use of telemedicine
The determinants of home healthcare robots adoption: An empirical investigation	International Journal of Medical Informatics	0,954	Alaiad and Zhou (2014)	Effects of technologies that employ robots in home health care

(continued)

State of The Art in Adoption of E-Health Services in Italy in The Context of European Union E-Government Strategies	Procedia Economics and Finance	-	Domenichiello (2015)	Degree of e-Health services foreseen by law; Intensity of use of e-Health by citizens
Identifying barriers in telemedicine-supported integrated care research: scoping reviews and qualitative content analysis	Journal of Public Health	0,812	Harst et al. (2019)	Implementing telemedicine in integrated care environments
5G in healthcare: how fast will be the transformation?	Irish Journal of Medical Science	0,323	Dananjayan and Raj (2020)	Integration of telemedicine into patient routines
Advancing beyond the system: telemedicine nurses' clinical reasoning using a computerized decision support system for patients with COPD – an ethnographic study	BMC Medical Informatics and Decision Making	0,908	Barken, Thygesen and Söderhamn (2017)	Integration of telemedicine into medical routines; Improved algorithms for telemedicine
Exploring factors associated with the uneven utilization of telemedicine in Norway: a mixed methods study	BMC Medical Informatics and Decision Making	0,908	Alami et al. (2017)	Macro analysis and holistic perspective for multidimensional and interdependent understanding of factors that influence telemedicine
Connected-Health Algorithm: Development and Evaluation	Journal of Medical System	0,686	Vlahu-Gjorgievska et al. (2016)	Improvement of algorithms aimed at technological developments in health
How do business model and health technology design influence each other? Insights from a longitudinal case study of three academic spin-offs	Research Policy	3,246	Lehoux et al. (2014)	Business models and innovation in healthcare
Risk management-based security evaluation model for telemedicine systems	BMC Medical Informatics and Decision Making	0,908	Kim, Choi and Han (2020)	Cyber risk models
A systematic scoping review of change management practices used for telemedicine service implementations	BMC Health Services Research	0,995	Kho, Gillespie and Martin-Khan (2020)	Changes in practices and processes aimed at implementing telemedicine; Barriers to the implementation of telemedicine
Systematic Review of Real-time Remote Health Monitoring System in Triage and Priority-Based Sensor Technology: Taxonomy, Open Challenges, Motivation and Recommendations	Journal of Medical Systems	0,686	Albahri et al. (2018)	Sensor optimization in telemedicine
E-Health, another mechanism to recruit and retain healthcare professionals in remote areas: lessons learned from EQUI-ResHuS project in Mali	BMC Medical Informatics and Decision Making	0,908	Bagayoko et al. (2014)	Perception of health professionals regarding the use of telemedicine
Acceptance and resistance of telehealth: The perspective of dual-factor concepts in technology adoption	International Journal of Information Management	2,881	Tsai et al. (2019)	End users' perception of the use of telemedicine
Adherence and factors affecting satisfaction in long-term telerehabilitation for patients with chronic obstructive pulmonary disease: a mixed methods study	BMC Medical Informatics and Decision Making	0,908	Hoaas et al. (2016)	End users' perception of the use of telemedicine
Analyzing older users' home telehealth services acceptance behavior—applying an Extended UTAUT model	International Journal of Medical Informatics	0,954	Cimperman, Brenčič and Trkman (2016)	End users' perception of the use of telemedicine

(concluded)

A feasibility study for the provision of electronic healthcare tools and services in areas of Greece, Cyprus and Italy	BioMedical Engineering OnLine	0,578	Mougiakakou et al. (2011)	End users' perception of the use of telemedicine; Integration of telemedicine into patient routines
A Literature Review on Attitudes of Health Professionals towards Health Information Systems: From e-Health to m-Health	Procedia Technology	-	Sezgin and Yıldırım (2014)	End users' perception of the use of telemedicine; Perception of health professionals regarding the use of telemedicine
Exploring the feasibility of eHealth solutions to decrease delays in maternal healthcare in remote communities of Ghana	BMC Medical Informatics and Decision Making	0,908	Pagalday-Olivares et al. (2017)	Network, security specifications, backup systems and m-Health privacy protocols
Economic evaluation of the utilization of telemedicine for patients with cardiovascular disease: a systematic review	Heart Failure Reviews	1,454	Farabi et al. (2019)	Cost and benefit ratio of telemedicine
Development of a user needs-based telepresence robot for consultation	Technology and Health Care	0,247	Lee and Kim (2020)	Robot usability tests for healthcare consultations

Source: prepared by the authors.

Vlahu-Gjorgievska *et al.* (2016) and Barken, Thygesen and Söderhamn (2017) suggested that future research should address the improvement of algorithms aimed at telemedicine, and Kiberu, Scott and Mars (2019) and Kho, Gillespie and Martin-Khan (2020) suggested that future studies should address obstacles to the implementation of telemedicine. The journals Procedia Economics and Finance and Procedia Technology, both from Elsevier, were discontinued in 2017 and 2018, so an indication of the SJR factor is not shown in the Table above.

LITERATURE RESEARCH TRENDS AND DISCUSSION OF THE MAIN THEORETICAL POINTS

During this bibliographical analysis, one can identify aspects that indicate trends in the literature on technological development in telemedicine. In this section, these aspects are synthesized and discussed in their theoretical perspectives. First, Figure 10 was generated using Iramuteq, corresponding to the similarity analysis of the abstracts of all analyzed articles.

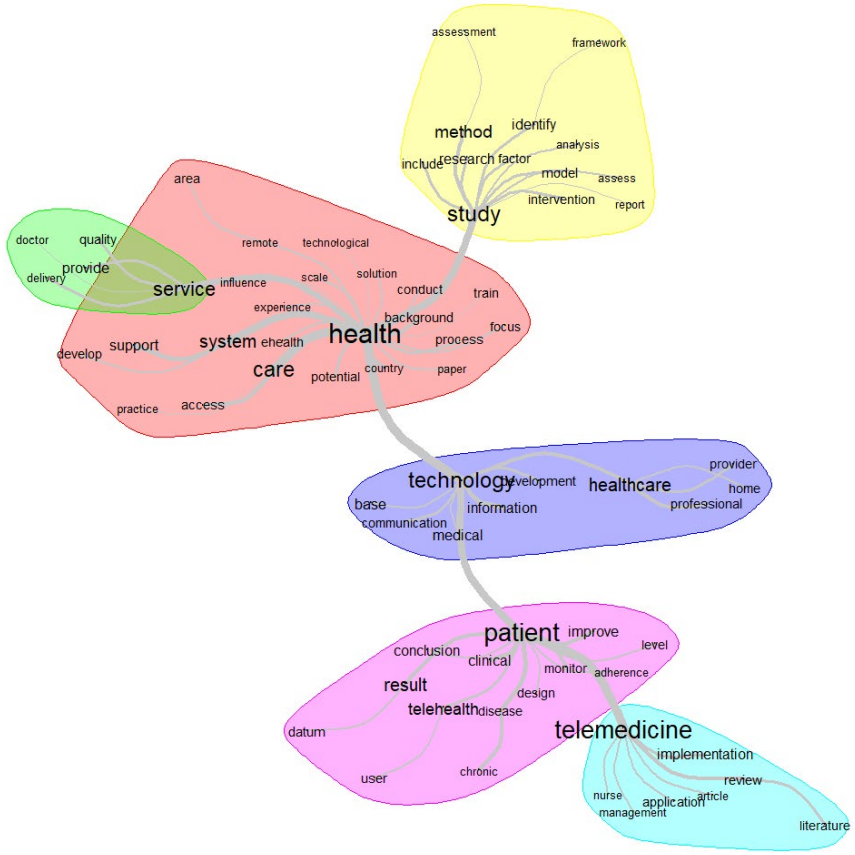

Figure 10 – Search classes in the literature
Source: prepared by the authors in Iramuteq.

Figure 10 shows that the central study class is "health," which unfolds directly into the "study," "service," and "technology" classes. This observation highlights that the health care system has straight links with the study and development of methods and models to operate e-Health systems (study), especially the provision of health services (service), facilitated by technological development (technology). The "technology" class, in turn, extends to the "patient" class, the user of telemedicine services provided by digital means. Finally, the "telemedicine" class, linked to the "patient" class, contains literature review articles on this field of study, which is emerging in the literature, and which focus either on service management and/or on the modes of its implementation.

When examining Figure 10 in detail, the term "conduct," which is in the "health" class, clearly connects the discussions to the "study" class, which in turn is subdivided into the investigation of methods, models, and frameworks aimed at technological development in telemedicine, as well as in their evaluation. The themes addressed in this last class address frameworks on the "regulation" of e-Health (Troshani; Goldberg; Wickramasinghe, 2012), models and "business opportunities" of telemedicine (Grustam *et al.*, 2017; Lehoux *et al.*, 2014) – also highlighted in Figure 11, methods for providing financially viable health services in remote areas (Crawford *et al.*, 2018), frameworks on the use of Information and Communication Technologies (ICTs) and 5G infrastructure in telemedicine planning (Anwar; Prasad, 2018), and use of the Analytic Hierarchy Process (AHP) to understand what are the most important factors for designing and evaluating an e-Health system (Cancela; Fico; Arredondo Waldmeyer, 2015).

Also, in relation to the unfolding of the "health" class, the "service" class refers to texts that discuss the quality of telemedicine services and their idiosyncrasies, mostly addressed in the themes "end user perception" and "perception of health professionals," shown in Figure 11.

The "health" class includes texts with varied themes, since this is the central class. Nevertheless, there is a predominance of texts that address the topic "operation of the telemedicine service" (Figure 11). Moreover, we highlight the articles that seek to promote access to health by telemedicine in remote locations (Bagayoko *et al.*, 2014; Dananjayan; Raj, 2020; Mougiakakou *et al.*, 2011; Nikolaidis; Efthymiadi; Angelidis, 2019; Thobias; Kiwanuka, 2018), in emerging countries (Gebre-Mariam; Bygstad, 2019; Khan *et al.*, 2015; Ncube; Mars; Scott, 2020), and also to analyze the interoperability of the health service between countries (Domenichiello, 2015; Kautsch; Lichoń; Matuszak, 2017) and the systematization and development of an e-Health system based on user experience (Jalil *et al.*, 2019).

The "technology" class contains texts that refer to ways of offering telemedicine services via "digital platforms" and "robotics" (Figure 11), as in Hardisty *et al.* (2011) and Alaiad and Zhou (2014). Texts that address the "perception of health professionals" (Figure 11) regarding the use of technology in telemedicine are also part of this class, as in Lu *et al.* (2020).

There is a strong link between the classes "technology" and "patient," given that the design of telemedicine systems depends on the perceptions of users, whether they are patients or health professionals; also, the improvement of the systems already available comes from the experiences of users. The service design, still little explored in this text, was approached by Eyles *et al.* (2016) and, in Table 6, it appears as a suggestion for future research. This class also presents articles that deal with the "operation of the telemedicine service" (Figure 11).

The "telemedicine" class includes studies that address the implementation and management of telemedicine services, discussed in the theme "telemedicine service management" (Figure 11), in addition to the literature review studies on the field of study, where it is also an emerging theme, as in the articles by Mosa, Yoo and Sheets (2012), Rojas-Mendizabal *et al.* (2013), Amadi-Obi *et al.* (2014), Sezgin and Yıldırım (2014), Eyles *et al.* (2016), Walters, Scott and Mars (2018), Farabi *et al.* (2019), Harst *et al.* (2019), Albahri *et al.* (2018), Castaneda and Ellimoottil (2020), Grimes *et al.* (2020), Huang *et al.* (2020), Kho, Gillespie and Martin-Khan (2020), Ncube, Mars and Scott (2020) and Xie *et al.* (2020).

The study classes discussed were associated with research themes, to discuss the theoretical aspects covered in the articles. However, this association is not exact, given that a text can fit more or less into one class and a theme is not necessarily linked to a single class. Figure 11 summarizes the themes found in the literature and the remainder of this section is dedicated to their analysis.

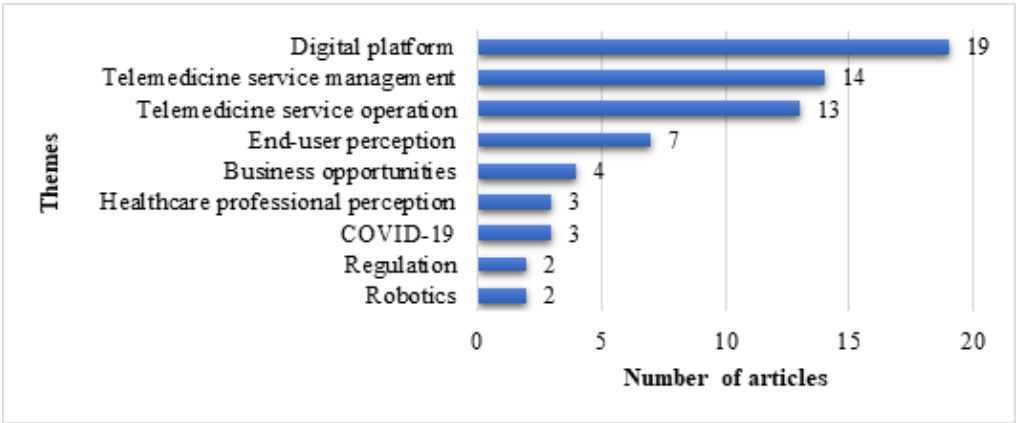

Figure 11 – Research topics in the literature
Source: prepared by the authors in Excel.

The theme "digital platform" was the most frequent (19 articles), given the interest in making the telemedicine service available via electronic platforms, in particular via smartphones (Balakrishnan *et al.*, 2016; Barken; Thygesen; Söderhamn, 2017; Eyles *et al.*, 2016; Harzheim *et al.*, 2016; Lee *et al.*, 2018;

Mougiakakou *et al.*, 2011; Parmanto *et al.*, 2015; Thobias; Kiwanuka, 2018), in addition to the development of an algorithm for telehealth (Vlahu-Gjorgievska *et al.*, 2016).

The theme "telemedicine service management" (14 articles) contains articles that address risks (Kim; Choi; Han, 2020), obstacles (Harst *et al.*, 2019), strategies (Ncube; Mars; Scott, 2020), integration with public health services (Kiberu; Scott; Mars, 2019), ecosystems (Rojas-Mendizaba *et al.*, 2013), and quality of service provision (Nikolaidis; Efthymiadi; Angelidis, 2019), in addition to literature reviews.

The "telemedicine service operation" (13 articles) covers articles that mainly deal with experiments on the use of telemedicine for monitoring patients and/or treating diseases (Albahri *et al.*, 2018; Cancela; Fico; Arredondo Waldmeyer, 2015; Castaneda; Ellimoottil, 2020; George; Cross, 2020; Hoaas *et al.*, 2016; Huang *et al.*, 2020; Joshi; Woll, 2015; Koehler *et al.*, 2020; Martin *et al.*, 2012; Wahba *et al.*, 2020;), in addition to containing literature reviews that address the same theme.

The "end-user perception" about the telemedicine service (7 articles) is addressed by Currie, Philip and Roberts (2015), Van Velsen *et al.* (2015), Cimperman, Brenčič and Trkman (2016), Dekker-Van Weering, Vollenbroek-Hutten and Hermens (2016), Petcu *et al.* (2017), Jalil *et al.* (2019), and Tsai *et al.* (2019) whereas "healthcare professional perception" (3 articles) is addressed by Sezgin and Yıldırım (2014), Crawford *et al.* (2016) and Lu *et al.* (2020).

The theme "business opportunities" (4 articles) refers to telemedicine benefitting from the development of 5G technology (Anwar; Prasad, 2018; Dananjayan; Raj, 2020) and the influence of the business model on service provision (Grustam *et al.*, 2017; Lehoux *et al.*, 2014). The legal aspects of telemedicine, addressed in the theme "regulation" (2 articles), were considered by Troshani, Goldberg and Wickramasinghe (2012) and Kautsch, Lichoń and Matuszak (2017).

Regarding the topic "robotics" (2 articles), Alaiad and Zhou (2014) analyzed the use of robots for health care at home, and Lee and Kim (2020) researched about the development of a robot to perform consultations. The three articles dealing with the topic "covid-19" addressed the use of telemedicine to care for patients during the coronavirus pandemic (Grimes *et al.*, 2020), the continuing medical education on diagnosis and treatment of diseases by digital platforms (Eisenstein *et al.*, 2020), and the role of telehealth during the pandemic (Monaghesh; Hajizadeh, 2020).

It is important to note that although Figure 6 (Word cloud of all keywords) and Figure 10 (Search classes in the literature) were generated by different software, the results are homogeneous, which denotes the effectiveness of the global analysis of the survey data.

CONCLUSIONS

This article analyzed the literature from the past ten years on technological development in telemedicine, aiming to depict the field of study and identify its scientific gaps and research trends. Searches for standardized keywords were carried out in five databases: Springer Link, Science Direct, Wiley Online Library, Web of Science, and Scopus, which, after selection and extraction of articles by StArt software, resulted in the analysis of 67 articles.

As a result, this bibliometric study characterized the evolution of the literature on technological development in telemedicine in the past ten years in terms of the most frequently cited areas of research, keywords, and articles, as well as the authors, journals, countries and research institutions with most research in the field of study and most used research methodologies. Furthermore, it identified the scientific gaps and research trends, as well as discussing the main theoretical points addressed in the analyzed articles. The bibliometric analysis was adequate to the research scope and its objectives were achieved.

The results showed that, in 2020, there was a significant increase in the number of publications about technological development in telemedicine, mainly because of covid-19. The research areas of the analyzed articles are management (52.2%), IT (25.4%), and medicine (22.4%), which confirms that telemedicine is

considered a frontier field of study in these research areas. The keywords used by the authors indicate the themes frequently addressed in the articles, and the ten most frequent were: technology, telemedicine, e-Health, m-Health, telehealth, telecare, IoT, literature review, healthcare, and innovation.

The most significant article in the field of study is "A Systematic Review of Healthcare Applications for Smartphones," by Mosa, Yoo and Sheets (2012), with 1,100 Google Scholar citations, and authors Maurice Mars and Richard Ernest Scott are the ones who have more articles published in this field, with three articles each, published in co-authorship. The low frequency of publications per author in the area, as well as the emergence of publications in 2020, indicate that this is a new research area, whose scope is still under construction, and that it is an area of growing interest for new studies. BMC Medical Informatics and Decision Making is the most cited journal in this field of study, followed by BMC Health Services Research, both owned by BioMed Central Ltd.

Authors from the United States of America have the highest number of articles published in the literature on technological development in telemedicine, and there is no research institution that stands out in terms of the number of articles published. The research approach preferred by the authors is qualitative (67.2%), followed by quantitative (20.9%) and mixed (11.9%). Concerning procedural methods, statistical procedures are more frequent (20.9%), as they represent the procedure method of all quantitative research, followed by structuralist, monographic, and functionalist methods, frequent in qualitative research, with 10.4% each. The most repeated research techniques are bibliographic research, extensive direct observation, and intensive direct observation, in that order.

Research trends were obtained by similarity analysis, using the Iramuteq software, which indicated the existence of six frequent classes of research. The central research class is "health," which unfolds directly into the "study," "service," and "technology" classes. The "technology" class, in turn, extends to the "patient" class, which progresses to the "telemedicine" class. Naturally, each research class represents a set of themes.

The main research topics addressed in terms of technological development in telemedicine are "digital platforms," "telemedicine service management," and "operation of the telemedicine service," the latter addressing the ways in which health professionals can monitor the clinical condition of patients and treatment of diseases by telemedicine. In sequence and in descending order of frequency, there are the themes "end user perception," "business opportunities," "perception of health professionals," "covid-19," "regulation," and "robotics".

Suggestions for future research are the scientific gaps themselves, summarized in Table 6. The limitations of the research come from the subjective analyses carried out by the authors to classify the articles in terms of research area (Figure 4) and themes (Figure 11), as well as the identification of the methodological procedures used by the authors in the analyzed articles, since they do not refer to data extracted directly from the texts, but rather inferred from their reading.

As far as practical contributions are concerned, this research helps to identify scientific gaps in co-design e-Health processes and regulatory mechanisms, since major approaches and trends in the literature focused on service design in digital platforms. This was further enhanced by the perception of health professionals and patients, allowing researchers to direct their future research, as well as reinforcing the need for further research on various topics of technological development in telemedicine. Furthermore, this study is a guide to understanding the research area in question.

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