The evolution and mapping trends of mobile health (m-Health): a bibliometric analysis (1997–2023)

Turki Alanzi[1], Shafiq Ur Rehman[2]^, Muhammad Ajmal Khan[3], Robert S. H. Istepanian*

[1]Department of Health Information Management and Technology, College of Public Health, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia; [2]Institute of Information Management, University of the Punjab, Lahore, Pakistan; [3]Directorate of Library Affairs, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia

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Correspondence to: Shafiq Ur Rehman, PhD. Institute of Information Management, University of the Punjab, Quaid-e-Azam Campus, 54590 Lahore, Pakistan. Email: shafiq.im@pu.edu.pk.

Background: Mobile health (m-Health) is widely acknowledged as a pivotal domain for improving global healthcare and driving its digital health transformation. Despite the vast amount of literature published in recent years, bibliometric studies on m-Health remain limited in scope and coverage. This study presents a comprehensive review of m-Health literature extracted from Scopus and PubMed databases, spanning the period from 1997 to 2023, including publications during the coronavirus disease 2019 (COVID-19) pandemic.
Methods: The combined Scopus and PubMed databases were used in this study. The search formula for the literature retrieval used the most appropriate and relevant keywords to m-Health. The bibliometric data importation, extraction and analysis of authors, titles, publication date, publication place, publisher, volume number, issue number, citation count, document type, author keywords, affiliation were all carried out using the 'Biblioshiny', 'EndNote X9®', 'Microsoft Excel®' and 'Microsoft Access®' software tools. Duplicate records were manually identified and removed. Visualization maps illustrating the recurrent keywords, collaboration patterns, and prolific publishing countries were generated using 'VOSviewer®'.
Results: A total of 37,470 (20,703 from Scopus and 16,767 from PubMed) publications were selected for the literature analysis. The results provided the definitive literature evidence on the origin of the concept of m-Health in 2003. Significant increase in the publications followed the global surge of smart phones usage in 2007, and the emergence of m-Health applications (Apps) and their global markets and ecosystems. The number of the publications peaked between 2013 and 2022 with most citations in 2022. There was noticeable spike in m-Health literature during the COVID-19 pandemic. The results also showed that most of the highly cited publications, leading institutions, and most prolific authors were predominantly from the developed countries. The USA has the highest number of publications followed by the UK, Australia, Germany, Canada and China, with most of the prolific authors originating from these countries.
Conclusions: In conclusion, while there has been a remarkable increase in global m-Health publications since 2003, most of the impactful literature and publications in this area originated from selected countries in the developed world. The study indicates a significant disparity between the published literature from developed compared to the developing countries. Addressing this disparity, further bibliographical studies are required to address these and other literature gaps.

Keywords: Mobile health (m-Health); telemedicine; digital health; bibliometric

*, Robert S. H. Istepanian was a visiting Professor at the Institute of Global Health Innovation, Imperial College, London, UK, and a distinguished professor College of Public Health, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia. Personal web: https://ristepanian.com/
^ ORCID: 0000-0002-8169-0132.

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Introduction

For nearly two decades, mobile health (m-Health) was hailed as the most innovative and enabling area for the global digital transformation of healthcare (1,2). This vital area was globally praised by key policymakers and experts alike as 'the biggest technology breakthrough of our time', and its use would 'address our greatest national challenge' (1).

Since then, numerous m-Health systems and applications (Apps) have been applied globally in almost every conceivable medical discipline, healthcare monitoring, and wellness area (1-5). M-Health's global popularity and transformative nature (1,4,5) are reflected in the extensive scientific literature, massive m-Health markets, phone-based m-Health Apps and ecosystems, and global businesses and services established over the last two decades. However, the origin of m-Health remains a 'known unknown' (2), although largely acknowledged and widely disseminated in the relevant literature (1,4,6) for the last two decades. The earliest cited literature on the evolution of the term m-Health indicates that the beginnings of the concept can be dated back to 1997 when the earliest genesis of the concept was referred to as 'wireless telemedicine' or 'mobile telemedicine' (7,8). These were followed by the publications citing the term 'unwired e-med' in 2000 (9). These publications represent earliest precursor terms that formed the basis for the subsequent introduction of the term m-Health in 2003. It is well known that m-Health originated in the seminal and pioneering work of Istepanian *et al.* in 2003. This work has been widely acknowledged by numerous scientific and literary publications since then (1,2,4,6). It was first defined as 'emerging mobile computing, medical sensor and communication technologies for healthcare' (3,10). These beginnings of m-Health and the original definition have not been widely documented in the literature *prima-facie* until recently (1,2,4,6). These were neither addressed in earlier bibliometric studies due to the scope and other limitations of these studies.

This definition reflects the critical technological and scientific principles of m-Health. These are shown in *Figure 1*.

This definition remains an acceptable notion and the cornerstone of the scientific understanding of m-Health (2). These pillars underpin the underlying scientific and technological principles of computing, communications, and sensing technologies applied to healthcare, encapsulating the basics of m-Health science (2). Furthermore, these principles and their constituent areas continuously evolve, with some emerging more robustly than others within the m-Health domain. There have been unprecedented advances in the computing and communication pillars encapsulated in the developments of artificial intelligence (AI), new intelligent wearable technologies, and sixth generation (6G) mobile communications for m-Health and digital health. The details of these technological

Highlight box

Key findings

- The definitive bibliometric and literature evidence on the origin and the earliest publications of mobile health (m-Health). The bibliometric literature data were extracted from Scopus and PubMed databases.
- Most of the high impactful and cited literature, top research institutions and prolific authorships originate from select number of high-income countries.
- The USA, UK, Canada, Australia are leading the research and literature publications in m-Health.
- There has been a notable surge in publications since 2007, with peaks in the period (2013–2022). This surge coincided with the massive global markets of [m-Health application (Apps)] and their diverse Apps. Another surge was noticeable following the coronavirus disease 2019 (COVID-19) pandemic.

What is known, and what is new?

- Previous studies have provided bibliometric analysis of scientific literature on m-Health highlighting the leading countries, institutions, journals, and topics between 2000–2020, using data from Scopus or Web of Science databases.
- This study presents new bibliometric information on the most prolific countries, authors, research institutions, top journal publishing in m-Health from 1997 to 2023 combing Scopus and PubMed databases. This includes the relevant literature during the COVID-19 pandemic.

What is the implication, and what should change now?

- The outcomes of this study warrant further literature and bibliometric studies to address many unanswered yet relevant issues. These include the crypto correlation between 'm-Health applications' and 'digital health applications' and the 'known unknowns' of grouping the former within the latter, especially in the most recent and relevant literature.

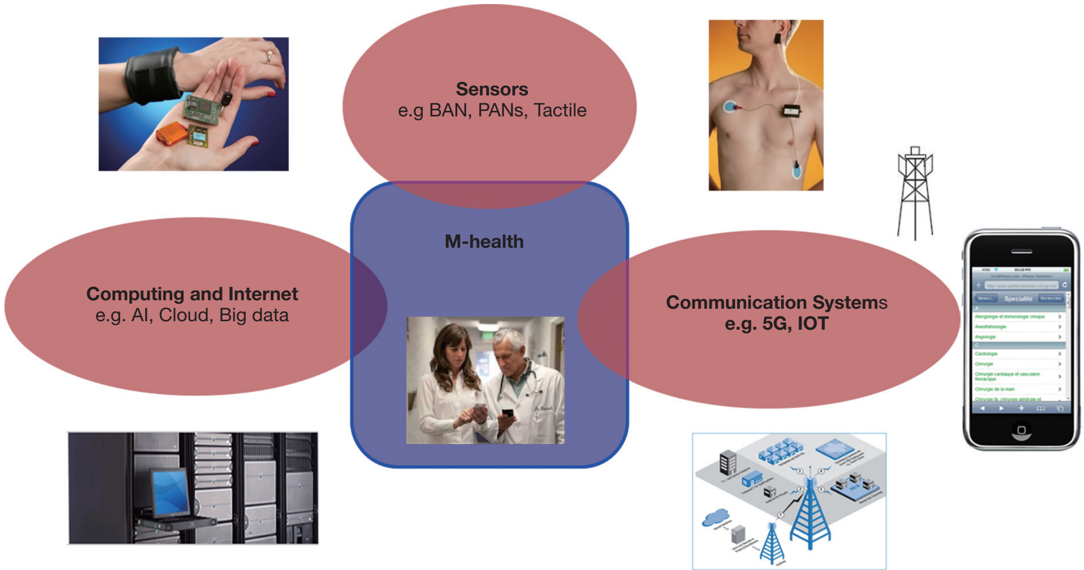

Figure 1 The fundamental technological and scientific pillars of m-health (1). Adapted from Istepanian RSH, Woodward B. m-Health: Fundamentals and Applications. Hoboken, NJ: John Wiley & Sons, Inc., 2017 with permission. AI, artificial intelligence; BAN, body area network; PANs, personal area networks; m-health, mobile health; 5G, fifth generation; IOT, internet of things.

developments are beyond the scope of this paper, and are described elsewhere (1).

Since its inception, m-Health has been hailed by many leading healthcare experts, clinicians, global institutions, influential business leaders, and most importantly, policymakers 'as the greatest and the biggest technology breakthrough of our time' (5).

In 2011, the World Health Organization (WHO) stated that m-Health has 'the potential to transform the face of health service delivery across the globe' (2,11). The organization defined m-Health as 'covering medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices' (2,11). However, this widely disseminated WHO report has neither cited nor referred to original publications nor the original definition of m-Health (2). This significant lapse in literature remains a 'known unknown' and ambiguous to date.

It is also worth noting that the m-Health Apps areas have dominated the m-Health literature since the introduction of the first generation of smartphones in 2007. It has been reflected in the exponential increase in the rate of relevant publications since then.

This influential technological milestone completely transformed the paradigm of m-Health and significantly contributed to its rapid evolution (1). However, these developments and the pivotal role played by smartphone technologies have been both a blessing and a curse for m-Health (1). Although these technological breakthroughs in mobile and internet communication technologies encapsulated by these smart devices have firmly placed m-Health on the global radar, many m-Health proponents view it as another global healthcare application market and a profitable opportunity (1,12). Nonetheless, this widely acknowledged interpretation of m-Health has been reflected in the exponential rise and global markets of the m-Health Apps in numerous health and wellness areas since 2007.

To reflect on this key milestone, a preliminary survey by the authors found that more than 400 literature and meta-analysis review studies were published between 2009 and 2019. These studies addressed numerous smartphone-based m-Health application areas and covered different areas such as healthcare monitoring, clinical, wellness, disease management, behavioral change, remote diagnostics, education, and other disciplines. Some of the most studied areas included m-Health Apps for non-communicable and chronic disease management, such as diabetes, cardiovascular disease, chronic obstructive pulmonary disease (COPD), and cancer (13,14); wellness and physical activity monitoring (15,16); remote diagnosis and treatment (17,18); patient education, mental health, and behavioral change (19-25); home and elderly care (26-28), public and global health (29-31); medical training and learning (32-34); primary and emergency care (35,36). More recently, many studies on m-Health and digital health Apps related to the coronavirus disease 2019 (COVID-19) pandemic have been published (37). The complete citations and analysis of these literature reviews and meta-analysis studies are beyond the scope of this paper, but are presented here for completeness.

This extensive m-Health literature reviews and studies have not been paralleled with corresponding bibliometric studies. Few studies have been published in recent years (38-41). The earliest (38,39) had many search limitations, bibliometric research scope shortcomings, and analysis gaps. These limitations, presented in further detail elsewhere (40,41), included a lack of accurate citations on the origin and first publications, lack of a definitive definition of m-Health, limited selection and selection of the search database [e.g., Web of Science (WoS)], limited timeframe of the search period used, and also the limited selection of the most relevant search keywords in the search methodologies. For example, one of these earlier studies based their search on a single keyword ‘mobile health’ with specific search timeframe (2006–2016) (38). Furthermore, the selection of these search dates, particularly of the beginning period, were neither clarified nor justified and remain contestable. It is well known that key publications and literature on m-Health was published prior to 2006, and neither of these studies had cited or included these. These studies had also excluded the numerous books and book chapters published in this area, these can also be considered major limitations of these bibliometric studies (38,39). Most importantly, these bibliometric studies focused mainly on the productivity of the publications (frequency of publication) and did not provide appropriate citations and relevant analysis of the most productive countries, organizations, and top journal publishers in this area (38,39). A recent bibliometric study (40) also had a significant limitation, as it listed only the most prolific authors based on the literature data extracted from a single albeit highly cited journal: *JMIR Mhealth Uhealth*. Furthermore, the literature data analyzed in this study was limited to the 676 abstract citations extracted from PubMed and limited only for the period 2013–2018. Furthermore, this study does not present an accurate bibliometric evolution with an overall historical trend in this area, but focused on singular and niche bibliometric outcomes of the most prolific authors and for specific time frame.

This paper presents a new and more comprehensive bibliometric study on m-Health from the period from 1997 until 2023 using two major scientific and medical databases most relevant to this area (Scopus and PubMed). The paper will also highlight the origin, evolution of m-Health, and discuss the results and future work in this area.

Methods

Database selection and search dates

This study analyzed the m-Health research productivity between 1997 and 2023 using the combined Elsevier’s Scopus and PubMed databases. The Scopus database was selected as one of the world’s leading scientific multidisciplinary databases, with broader coverage than the WoS used in earlier studies. This is particularly important and relevant to m-Health, as these databases combined represent the largest and most comprehensive literature coverage in health and medical-related disciplines (42). It is also well known that the WoS database has a lesser cited literature spectrum compared to the broader coverage provided by Scopus and PubMed, especially in the above disciplines (43). For example, PubMed database is considered the most popular in biomedical literature including the m-Health literature, as it contains more than 35 million citations and abstracts of biomedical literature and related areas. Hence, the selection of these two databases is considered the most relevant to the m-Health research and for bibliometric studies and search methodology used in this area.

The bibliometric data search and review process was conducted until 17th July 2023, as the cutoff date selected for this study. More recent literature published since then will most likely be statistically insignificant to impact the final data analysis and results obtained from this study due to the large number of publications analyzed from the preceding years compared to the number cited in more recent publications.

Keyword selection and literature search methodology

Considering the factors of high recall precision and retrieval of the maximum number of relevant publications, we applied a broader spectrum of the most relevant keywords to the search methodology used. The following query was run to obtain the data from the databases: *(TITLE ((mhealth* OR m-health* OR “digital health*” OR “wireless telemedicine” OR (health AND “Personal Digital Assistant*”) OR (health AND pda?) OR “wireless e-med*” OR “wireless emed*”)) OR AUTHKEY ((“Mobile health” OR mhealth* OR m-health* OR “digital health*” OR “wireless telemedicine” OR*

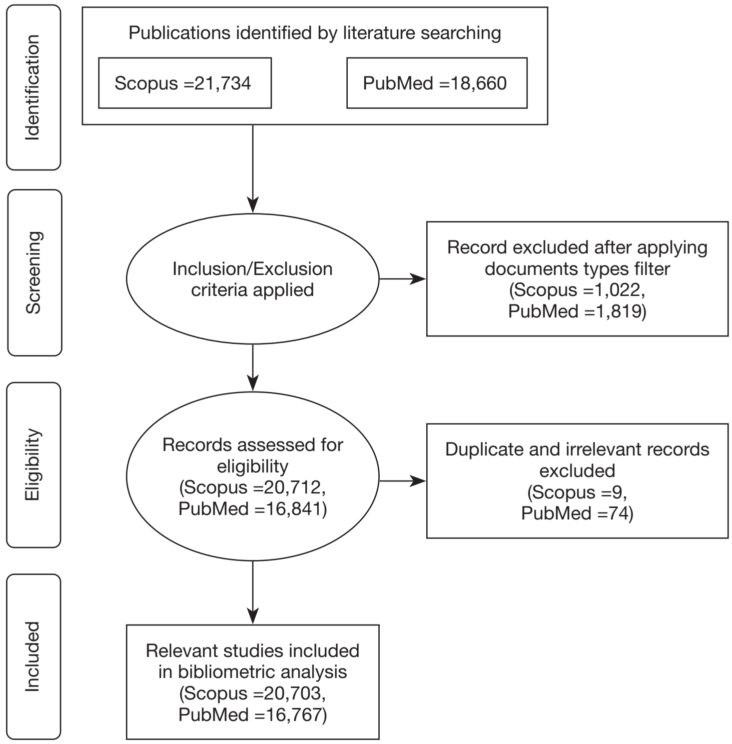

Figure 2 Data extraction and filtration process.

(health AND "Personal Digital Assistant") OR (health AND pdas) OR "wireless e-med*" OR "wireless emed*"))) AND NOT TITLE-ABS-KEY ("mobile unit" OR "mobile health clinic*" OR "health Unit" OR van OR transport OR "Digital Health Sciences Librar*") AND PUBYEAR > 1996 AND PUBYEAR < 2024.*

These keywords and combinations represent the most widely used and applicable search keywords examined in the publications and the identified documents within the two selected databases (Scopus and PubMed). The inclusion criteria used in the search process were chosen to select all research articles, full conference papers, review papers, books, and book chapters published in any language. The exclusion criteria included editorials, notes, letters, errata, short surveys, conferences, and summary articles written in any language. We also excluded the 'conference and meeting abstracts' as the Scopus database does not include these abstracts in their coverage, as stipulated in the Scopus content coverage guidelines (44). Furthermore, the selected publication's title and keyword as a search field were selected to standardize and limit any irrelevant results extracted from the database. These keywords and the records retrieved from this study represent a broader and more comprehensive spectrum of m-Health publications compared to the limited keyword selections and records of publications identified from earlier bibliometric studies (38,39). *Figure 2* shows the data extraction and filtration process used in this study. Each extracted record was rigorously checked for validity within/against the abovementioned inclusion criteria.

As shown in *Figure 2*, a total of 21,734 and 18,660 records were extracted from the Scopus and PubMed databases respectively. These included the full bibliographical data details (author name, document title, source title, publication date, publication place, publisher, volume number, issue number, citation count, document type, author keywords, affiliation, etc.). The data import, extraction, and analysis of the results were carried out using VOSviewer®, Biblioshiny, EndNote X9®, Microsoft Excel® and Microsoft Access® software tools.

Exclusions of records

As shown in *Figure 2*, 83 duplicates and irrelevant items (9 from Scopus and 74 from PubMed) were excluded from the final selection. A second criteria and validation process were

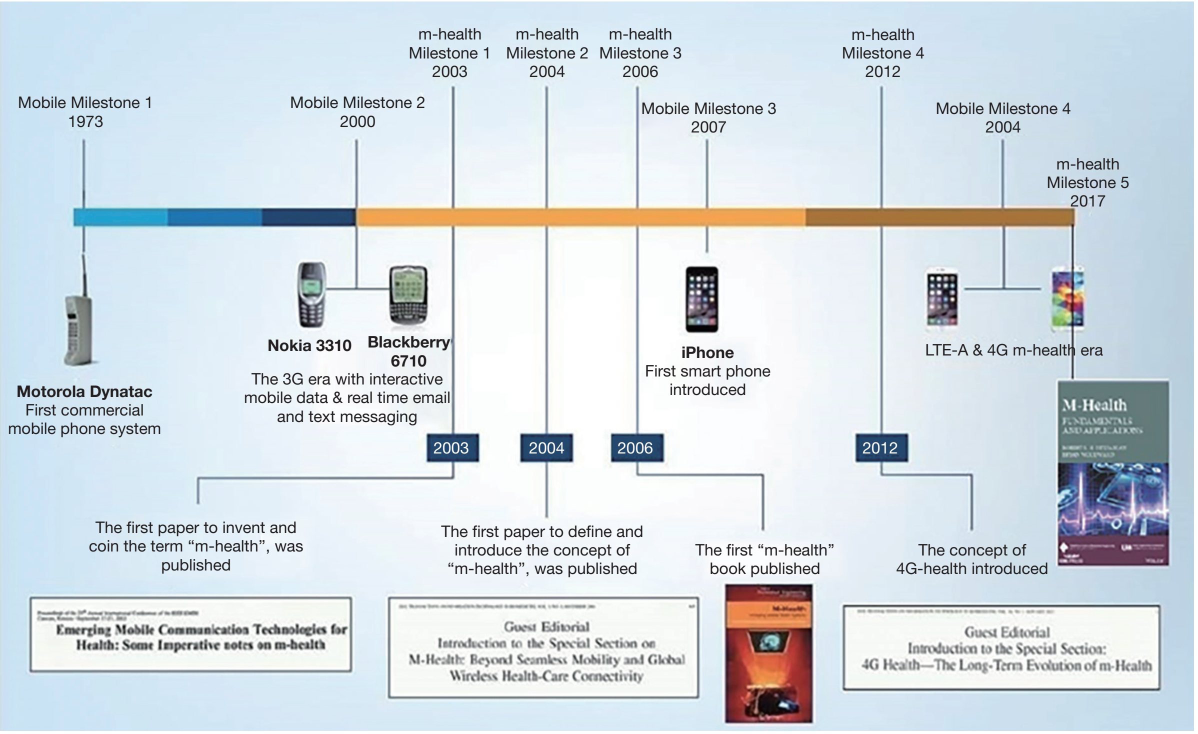

Figure 3 The historical perspective of the evolution of mobile health (1). Adapted from Istepanian RSH, Woodward B. m-Health: Fundamentals and Applications. Hoboken, NJ: John Wiley & Sons, Inc., 2017 with permission.

repeated to ensure the accuracy of the final selection of the identified records. A total of 37,470 records (20,703 from Scopus and 16,767 from PubMed) were selected and used for the final data analysis, as shown in *Figure 2*.

The extracted recorded data were then analyzed to identify clusters and present the data according to the leading publishing journals, prolific institutions, authors, countries, and institutions publishing in this area of research. In addition, the authorship and collaboration patterns were deduced from the most highly cited articles. A few fields/abbreviations are used in the various table columns in data analysis, such as total publications (TPs) and total citations (TCs).

Citations per publication (C/P) was used in this study and calculated by dividing the total number of citations by the total number of publications cited. This represents the average number of citations a specific publication has received (45). In contrast, the CiteScore (CS) measure, as specified by Scopus, determines the C/P based on Scopus data. This measure calculates the average number of citations received in a calendar year divided by all the items published within a specific journal in the preceding three years.

Results

Evolution and publication trends of m-Health literature (1997–2023)

Figure 3 illustrates critical historical and literature milestones of m-Health since its inception in 2003. However, in 1997, the first publication that coined the term 'mobile telemedicine' was published as the earliest precursor to m-Health. It highlighted the fundamental concepts of the mobility benefits and the feasibility of health data transmission capabilities associated with earlier Global System for Mobile Communication (GSM) cellular phone technologies for healthcare (7). This pioneering work laid the foundations and the principles for the subsequent publications that introduced the concept of m-Health in 2003. Hence, the selection of the search date used in this study was backdated to 1997 and attributed to this original publication date.

As shown in *Figure 3*, the introduction of third-generation (3G) communications and the dawn of the mobile internet data in the early 2000s was pivotal and key milestone that contributed to the introduction of the

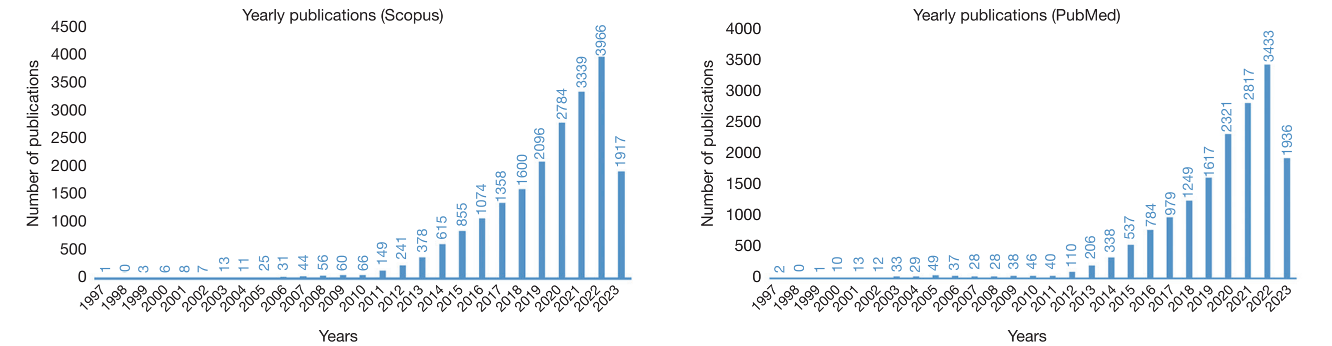

Figure 4 The chronological productivity of mobile health publications (1997–2023).

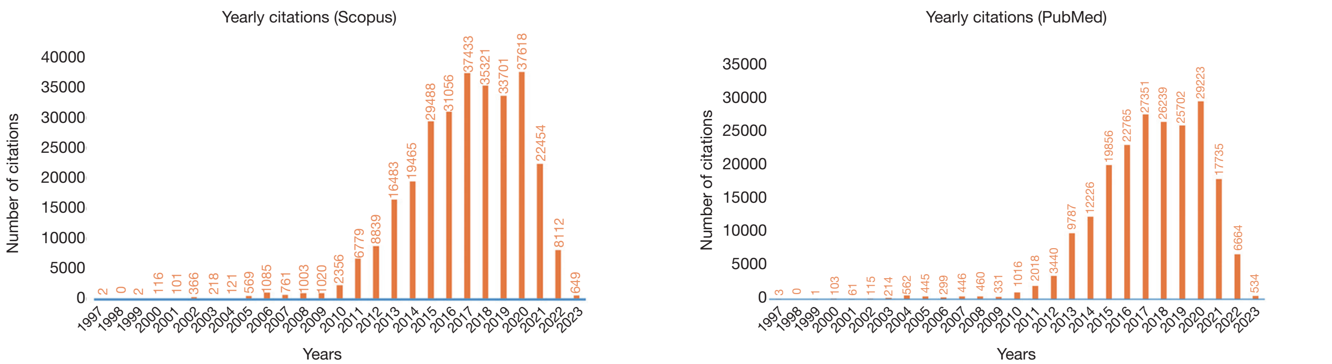

Figure 5 The chronological productivity of mobile health.

concept of m-Health in 2003 (3,10). and later to its leading to the first definition in in 2004 (3,10). Subsequently, the first edited book on m-Health was published in 2006 (8). The publication of this first book is also considered another milestone in the relevant literature and developments in different m-Health areas and Apps. Another key milestone evolved around the introduction of the first generation of smartphones in 2007 and the beginning of the m-Health App era. The concepts of '4G health' and '5G health' were later introduced in 2012 and 2017 respectively (1). These milestones represent the main evolutionary process of m-Health and the developments in this area from the technological and scientific perspectives.

Chronological productivity of m-Health publications

Figure 4 shows the chronological productivity and publication trends of m-Health literature since 1997. As discussed earlier, the first published research article laying the foundations for m-Health was published in 1998 by Istepanian *et al.* (7). This paper was initially published as a conference paper by the Royal Society in London, and illustrated the earliest representation of the concept as 'mobile telemedicine', a precursor to the term m-Health. This pioneering work was subsequently published as supplement in the *Journal of Telemedicine and Telecare* (7).

Figure 4 also illustrates the sharp increase in the published literature following the introductory and seminal publications by Istepanian *et al.* in 2003 and 2004 (3,10). The search results also highlight that the first book on m-Health was published in 2006 (8). The publication of this seminal book triggered the popular trend of publishing numerous books and industry reports in this area. The figure also shows that the peak publication years were between 2013 and 2022. This publications trend peaked in 2022, with 3,966 publications, compared to 2,784 and 3,339 in 2020 and 2021, respectively.

Chronological productivity of m-Health citations

Figure 5 illustrates the productivity of m-Health citations between 1997 and 2023. The figure illustrates the sustained

Table 1 Global m-Health literature productivity on a country-by-country basis

Rank	Top 10 countries (Scopus)				Top 10 countries (PubMed)			
	Country	TP	TC	C/P	Country	TP	TC	C/P
1	United States	7,844	138,048	17.60	United States	6,048	94,695	15.66
2	United Kingdom	2,686	51,387	19.13	United Kingdom	2,039	35,220	17.27
3	Australia	1,803	33,064	18.34	Australia	1,351	21,756	16.10
4	Germany	1,562	17,398	11.14	Germany	1,109	11,601	10.46
5	Canada	1,362	21,624	15.88	Canada	1,080	15,295	14.16
6	China	929	14,524	15.63	Netherlands	720	11,303	15.70
7	Spain	891	16,661	18.70	Spain	628	10,295	16.39
8	Netherlands	880	15,449	17.56	China	567	6,131	10.81
9	India	823	9,833	11.95	Switzerland	548	7,391	13.49
10	Italy	785	12,063	15.37	Italy	467	6,817	14.60

TP, total publications; TC, total citations; C/P, citations per publication.

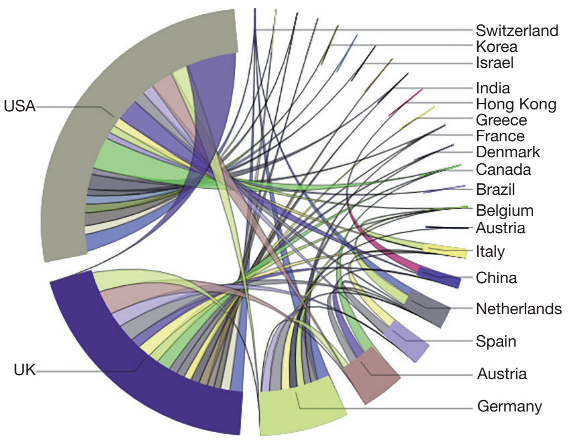

Figure 6 Visualization of the global collaboration of the top 20 countries/regions.

increase in citation levels since 2010, with 2,356 citations, followed by a sharp peak over the subsequent decade. This increase culminated in 2020 with a total of 37,618 citations. The figure also shows that the years with the most citations were from 2013 to 2022.

m-Health literature productivity by country

The analysis of global m-Health literature productivity is shown in *Table 1*. The summary of the top 10 countries, with their TPs, TCs, and their corresponding C/P, calculated individually. This table shows that in the Scopus data, the USA ranked first with 7,844 publications, 138,048 citations, and a C/P of 17.60, followed by the UK with 2,686 publications, 51,387 citations, and a corresponding C/P of 19.13. Similarly, Australia had 1,803, Germany had 1,562, and Canada had 1,362 publications.

These results also show a considerable gap between the total number of publications and citations from the USA and the corresponding number of publications and citations from other countries. However, from the perspective of C/P, there was no considerable difference between the USA and the other top five countries on the list. For example, Italy scored a citation level close to the citations from the USA despite having only 785 publications, compared to 7,844 from the USA.

The top five countries for their scientific publications in PubMed were similar to those in Scopus, except Switzerland, replacing India at number 9, with 548 publications, 7,391 citations, and 13.49 C/P. The USA had the most publications and citations, with their C/P within the top five countries remaining relatively similar, except Germany, which had a C/P of 10.46.

Global collaboration in m-Health publications

Figure 6 lists the top 20 countries/regions, where collaborated publications are greater than 70, and their historic collaborative patterns. These are distributed within the clusters shown and reflect the strength of collaboration patterns and corresponding joint publications between the countries and collaborating partners.

The USA and the UK had the most robust collaborations (547 publications), followed by the USA-Canada collaborations (349 publications), then the UK-Australia (269 publications), USA-Australia (252 publications), USA-China (245 publications), and UK-Germany collaborations (219 publications). These results indicate that the USA has been pivotal in global research, publications, and collaborations in the m-Health domain.

Top journal distribution

In recent years, several m-Health journals and leading scientific publications have continued to publish extensively in this area. This increasing interest reflects this research area's importance, continued global impact, and increased popularity within the publishing and scientific communities.

The list of the top twenty journals publishing on m-Health is shown in *Table 2*. The table also shows each journal's country of origin, TPs, CS, quartile rank (Q), TCs, and average C/P. The *JMIR Mhealth Uhealth* are ranked first with 1,258 publications and 29,145 citations, establishing a C/P of 23.17 in Scopus and PubMed with 1,356 publications, 25,058 citations, and 18.48 average C/P. This is followed by its sister journal, the '*Journal of Medical Internet Research*'. The '*JMIR Formative Research*' journal is ranked third on the list, with 613 publications, 1,985 citations, and 3.24 C/P in Scopus and 656 publications, 1,796 citations, and 2.74 C/P in PubMed. Ranking second on the list is the '*Journal of Medical Internet Research*', which had more citations (N=32,999) and a C/P of 29.54 compared to the above journals. This can be attributed to the long-established history of this journal and the longevity of its publications' records compared to the relatively newer (*JMIR*) journals. Furthermore, all the subsequent journals on the list, namely, *Studies in Health Technology and Informatics*, *JMIR Research Protocols*, *International Journal of Environmental Research and Public Health*, *Digital Health*, *Lecture Notes in Computer Science*, *Telemedicine and E-Health*, *and JMIR Mhealth Uhealth*, have relatively fewer numbers of publications compared to the top three journals on the list. Nevertheless, these journals show a significant increase in citations and corresponding C/P.

The table also shows the individual CS, Q, and citation metrics used by the Scopus database for each journal (42,44,45). The highest CS was 12.1 for '*Journal of Medical Internet Research*', compared to the lowest CS of 1.1 for '*The ACM International Conference Proceeding Series*'. It can also be noted that 11 journals on this list are within the highest quartile rank (Q1) category, except for those ranked in 3rd, 4th, 5th, 6th, 8th, 11th, 13th, 14th, and 19th positions. '*The ACM International Conference Proceeding Series*' at 11th position has no quartile.

Observing the same trend from PubMed, we found that, in general terms, the highest CS was for the same journals as those from the Scopus data. However, the lowest CS of 1.4 was allocated to '*Studies in Health Technology and Informatics*'. As shown in *Table 2*, for PubMed, the results list 11 journals within the highest quartile rank (Q1) category, except those ranked from positions 3 to 6, 10 to 12, 15, and 17, respectively.

Most prolific authors in m-Health

Table 3 shows the most prolific authors publishing on m-Health within the search period. This list was compiled by calculating the individual publications attributed to each author within the specified search period. The authors were then ranked by their total number of publications, single authorship, and first authorship patterns.

The table shows that the most prolific author is Torous J, with 95 publications in Scopus and 100 in PubMed, respectively, followed by Mohr DC, Schnall R, and Whittaker R, as listed from the Scopus and the PubMed databases.

Further analysis of the author's list shows that Istepanian RSH is the pioneering author in this area, with his earliest citation and publications record that date back to 1997. These are originally cited for the publications in on 'wireless telemedicine' and 'mobile e-Med' as precursor terms to the seminal publications on m-Health in 2003 and 2004 respectively. The earliest date of the extracted literature data from the combined Scopus and the PubMed databases indicates that the earliest publications were listed by Istepanian, with 34 publications, 1,233 citations, and a total C/P of 36.26. *Table 3* shows that the highest number of citations [4,713] are accredited to the second top author, Mohr DC, with 60 publications since 2011 in Scopus. The author Torous J had the highest number of citations [3,503] from 100 publications since 2014 as listed within the PubMed database. It is also of note that most of the top authors in this list had their publications in the post-2011 period, with consistency shown by the top four authors in both databases.

Table 2 The top 20 publishing journals in m-Health

Rank	Top 20 sources of Scopus							Top 20 sources of PubMed						
	Source	Country	TP	TC	C/P	CS	Q	Source	Country	TP	TC	C/P	CS	Q
1	*JMIR Mhealth and Uhealth*	Canada	1,258	29,145	23.17	10.9	1	*JMIR Mhealth and Uhealth*	Canada	1,356	25,058	18.48	10.9	1
2	*Journal of Medical Internet Research*	Canada	1,117	32,999	29.54	12.1	1	*Journal of Medical Internet Research*	Canada	1,169	25,753	22.03	12.1	1
3	*JMIR Formative Research*	Canada	613	1,985	3.24	2.1	2	*JMIR Formative Research*	Canada	656	1,796	2.74	2.1	2
4	*Studies in Health Technology and Informatics*	Netherlands	485	2,327	4.8	1.4	3	*JMIR Research Protocols*	Canada	502	2,860	5.7	2.6	2
5	*JMIR Research Protocols*	Canada	437	2,694	6.16	2.6	2	*Studies in Health Technology and Informatics*	Netherlands	426	1,142	2.68	1.4	3
6	*International Journal of Environmental Research and Public Health*	Switzerland	359	2,560	7.13	5.4	2	*International Journal of Environmental Research and Public Health*	Switzerland	380	2,003	5.27	5.4	2
7	*Digital Health*	United States	285	1,369	4.8	3.7	1	*Digital Health*	United States	334	1,733	5.19	3.7	1
8	*Lecture Notes in Computer Science*	Germany	208	1,186	5.7	2.2	3	*JMIR Mental Health*	Canada	206	3,568	17.32	9.2	1
9	*Telemedicine and E-Health*	United States	204	5,192	25.45	8.1	1	*Telemedicine Journal and E-Health*	United States	205	4,603	22.45	8.1	1
10	*JMIR Mental Health*	Canada	191	4,334	22.69	9.2	1	*Frontiers in Digital Health*	Switzerland	184	481	2.61	2.2	2
11	*ACM International Conference Proceeding Series*	United States	169	694	4.11	1.1	N/A	*Frontiers in Public Health*	Switzerland	173	701	4.05	3.8	1
12	*Frontiers in Public Health*	Switzerland	153	808	5.28	3.8	1	*Mhealth*	China	172	1,637	9.52	4.1	2
13	*Frontiers in Digital Health*	Switzerland	152	542	3.57	2.2	2	*Sensors (Basel)*	Switzerland	164	1,290	7.87	6.8	1
14	*JMIR Human Factors*	Canada	139	879	6.32	2.7	2	*BMJ Open*	United Kingdom	163	1,501	9.21	4.4	1
15	*International Journal of Medical Informatics*	Ireland	135	3,569	26.44	9.5	1	*International Journal of Medical Informatics*	Ireland	150	2,399	15.99	9.5	1
16	*BMJ Open*	United Kingdom	135	1,469	10.88	4.4	1	*JMIR Human Factors*	Canada	149	719	4.83	2.7	2
17	*BMC Public Health*	United Kingdom	134	2,681	20.01	6.1	1	*BMC Public Health*	United Kingdom	133	1,893	14.23	6.1	1
18	*BMC Medical Informatics and Decision Making*	United Kingdom	116	2,245	19.35	6.2	1	*BMC Medical Informatics and Decision Making*	United Kingdom	116	1,796	15.48	6.2	1
19	*Trials*	United Kingdom	105	891	8.49	3.6	2	*Trials*	United Kingdom	98	627	6.40	3.6	2
20	*Journal of the American Medical Informatics Association*	United States	93	2,713	29.17	11.7	1	*Journal of the American Medical Informatics Association: JAMIA*	United States	95	2,252	23.71	11.7	1

m-Health, mobile health; TP, total publications; TC, total citations; C/P, citations per publication; CS, cite score; Q, quartile rank; N/A, not applicable.

Table 3 The top 20 most prolific authors in m-Health

Rank	Top 20 Scopus authors						Top 20 PubMed authors					
	AU	TP	TC	C/P	S_Year	E_Year	AU	TP	TC	C/P	S_Year	E_Year
1	Torous J	95	3,789	39.88	2014	2023	Torous J	100	3,503	35.03	2014	2023
2	Mohr DC	60	4,713	78.55	2011	2023	Mohr DC	57	2,750	48.25	2013	2023
3	Schnall R	53	1,497	28.25	2012	2023	Schnall R	49	996	20.33	2013	2023
4	Whittaker R	52	2,307	44.37	2012	2023	Whittaker R	48	1,639	34.15	2012	2023
5	Schueller SM	51	3,363	65.94	2013	2023	Car J	48	926	19.29	2012	2023
6	Maddison R	47	2,035	43.3	2012	2023	Maddison R	42	1,482	35.29	2012	2023
7	Car J	47	1,533	32.62	2013	2023	Schueller SM	42	1,960	46.67	2014	2023
8	Pryss R	46	376	8.17	2018	2023	Jiang Y	41	832	20.29	2012	2023
9	Kowatsch T	41	678	16.54	2016	2023	Martin SS	38	804	21.16	2015	2023
10	Martin SS	40	943	23.58	2015	2023	Redfern J	38	642	16.89	2016	2023
11	Redfern J	39	763	19.56	2016	2023	Ben-Zeev D	36	979	27.19	2012	2023
12	Rodrigues JJPC	38	1,640	43.16	2008	2021	Bull S	35	302	8.63	2016	2023
13	Bousquet J	38	1,001	26.34	2017	2023	Spring B	33	1,257	38.09	2011	2023
14	Kotz D	38	760	20	2009	2022	Bousquet J	36	837	23.25	2017	2023
15	Wickramasinghe N	38	173	4.55	2005	2023	Parmanto B	36	956	26.56	2013	2023
16	Guo X	37	1,313	35.49	2012	2023	Kumar S	32	1,068	33.38	2012	2023
17	Ben-Zeev D	36	1,772	49.22	2012	2023	Kowatsch T	32	458	14.31	2016	2023
18	Istepanian RSH	34	1,233	36.26	1997	2022	Cafazzo JA	30	1,023	34.1	2012	2023
19	Naslund JA	34	756	22.24	2015	2023	Chow CK	32	441	13.78	2016	2023
20	Baumeister H	33	824	24.97	2017	2023	Labrique A	30	932	31.07	2014	2023

m-Health, mobile health; AU, author; TP, total publications; TC, total citations; C/P, citations per publication; S_Year, start year; E_Year, end year.

Authorship pattern

Figure 7 shows the authorship patterns of the publications identified in this study. The figure shows that out of the 20,703 publications extracted from Scopus, only 1,255 were written by single authors. Most (94%) were based on collaborative work and multiple authorships. The statistical analysis of the publications data indicated that the dominant authorship pattern was of four authors, with 3,008 publications, or 14.53% of the total. This was followed by three authors (14.4%) and five (12.68%) authors' patterns. The least number of publications was of the top 10 authors (3.24%). However, 3,531 publications, or 17.06% of the total, had more than 10 authorships. Overall, these results indicate that most m-Health publications are the outcomes of collaborative work and research.

Most productive institutions

Table 4 shows the top 20 institutions conducting global m-Health research. The results are based on their TP productivity and literature levels during the search period. The University of California, USA, is ranked first with 828 publications, 16,968 citations, and a 20.49 C/P in Scopus and 745 publications, 11,185 citations, and 15.01 C/P in PubMed. It is followed by Harvard University, USA, with 561 publications, 11,776 citations, and a C/P of 20.99 in Scopus and 533 publications, 9,251 citations, and 17.36 C/P in PubMed. The table also shows that most top institutions were from the USA (13 in Scopus and 12 in PubMed), followed by the UK (3 in Scopus and 4 in PubMed). Northwestern University, USA, is ranked first based on its C/P. Moreover, there are 12 institutions with a C/P over 20,

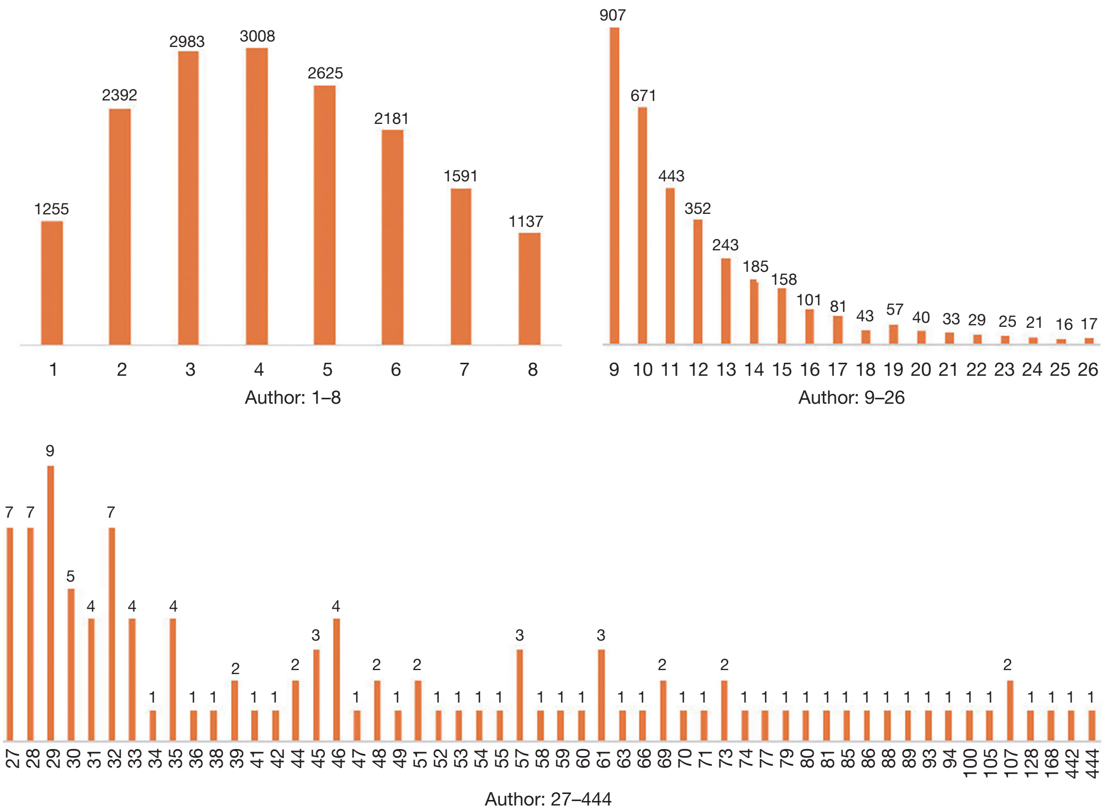

Figure 7 The authorship patterns related to mobile health publications.

and 8 of these are from the USA.

Most widely used keywords in m-Health literature (2003–2023)

The most widely used keywords and terms in m-Health-cited literature since 2003 are illustrated in *Figure 8*. These keywords were chosen to reflect the most popular and relevant keywords used widely in the relevant literature. The analysis shows that the top keyword used by authors in their abstracts, titles, and article keywords is "m-Health", with 5,170, 3,377, and 8,494 occurrences, respectively. The authors have used this keyword 'm-Health' in their published abstracts, titles, and article keywords since 2005. This keyword was also used within the 'index keywords' category and ranked 5th with 3,467 occurrences. It is important to note that this keyword was first selected and used in the database searches in 2004, following the seminal publications of Istepanian *et al.* (3,10), and not before this date.

Other top-used keywords used are 'Mobile Health', 'Smartphone', 'Health Care', 'Digital Health', 'Mobile App', 'eHealth', and 'Telemedicine' in abstracts, titles, and article keywords in 'Index Keywords' the top keyword is 'Health Care' with 5,210 occurrences, followed by 'Telemedicine', 'Mobile App', and 'Mobile Application' with 4,706, 3,876, and 3,802 occurrences respectively.

Discussion

This bibliometric study provided the most recent and comprehensive literature evidence on m-Health's origin, evolution, and global publication trends (m-Health). The recent increase in publications in this area, especially during the post-COVID-19 pandemic, reflects m-Health's importance and transformative traits in pandemic and post-pandemic periods. Globally. These results also show a considerable increase in the volume of relevant publications following the introduction of the first generation of smartphones in 2007. There was also a surge in publications in the post-COVID-19 pandemic period. The 2007 threshold milestone can be considered indicative of the beginning of the m-Health Apps era of m-Health, and an essential shift in the expansion of the publications in this area due to global market-driven interest and the much-

Table 4 Most prolific institutions in mobile health research and publications

Rank	Top 20 Scopus affiliations					Top 20 PubMed affiliations				
	Affiliation	Country	TP	TC	C/P	Affiliation	Country	TP	TC	C/P
1	University of California	United States	828	16,968	20.49	University of California	United States	745	11,185	15.01
2	Harvard University	United States	561	11,776	20.99	Harvard University	United States	533	9,251	17.36
3	University of Washington	United States	395	9,394	23.78	University of Washington	United States	351	6,419	18.29
4	University of Sydney	Australia	335	8,087	24.14	University of Sydney	Australia	316	4,934	15.61
5	University of Toronto	Canada	328	6,207	18.92	University of Toronto	Canada	312	3,481	11.16
6	University College London	United Kingdom	307	6,612	21.54	University College London	United Kingdom	289	5,713	19.77
7	University of Michigan	United States	270	6,732	24.93	Johns Hopkins University	United States	257	3,707	14.42
8	Northwestern University	United States	266	10,677	40.14	Northwestern University	United States	254	5,810	22.87
9	University of Oxford	United Kingdom	263	7,964	30.28	University of Michigan	United States	254	4,209	16.57
10	Stanford University	United States	261	5,344	20.48	Duke University	United States	234	3,365	14.38
11	Johns Hopkins University	United States	251	4,601	18.33	University of Oxford	United Kingdom	231	4,686	20.29
12	University of North Carolina	United States	237	3,659	15.44	Stanford University	United States	230	3,725	16.2
13	University of British Columbia	Canada	234	3,241	13.85	University of North Carolina	United States	229	2,586	11.29
14	Imperial College London	United Kingdom	231	5,650	24.46	Columbia University	United States	221	3,859	17.46
15	Columbia University	United States	230	5,188	22.56	Imperial College London	United Kingdom	217	3,786	17.45
16	Duke University	United States	223	4,564	20.47	King's College London	United Kingdom	208	2,959	14.23
17	University of Melbourne	Australia	220	4,330	19.68	University of Melbourne	Australia	192	3,167	16.49
18	University of Pennsylvania	United States	192	3,636	18.94	Massachusetts General Hospital	United States	183	2,166	11.84
19	Monash University	United States	192	3,181	16.57	University of Pennsylvania	United States	181	2,211	12.22
20	Massachusetts General Hospital	United States	187	3,516	18.8	Karolinska Institutet	Sweden	175	2,403	13.73

TP, total publications; TC, total citations; C/P, citations per publication.

anticipated costs, efficiency, clinical effectiveness, and other benefits associated with the smartphone-based Apps.

The results also show an increasing trend in the TPs, particularly from 2011, with a marked increase in COVID-19 (2020–2022). The most significant year of research productivity and publication from both databases (Scopus and PubMed) was in 2022, with a record volume of publications since 2003. These results also reflect a similar

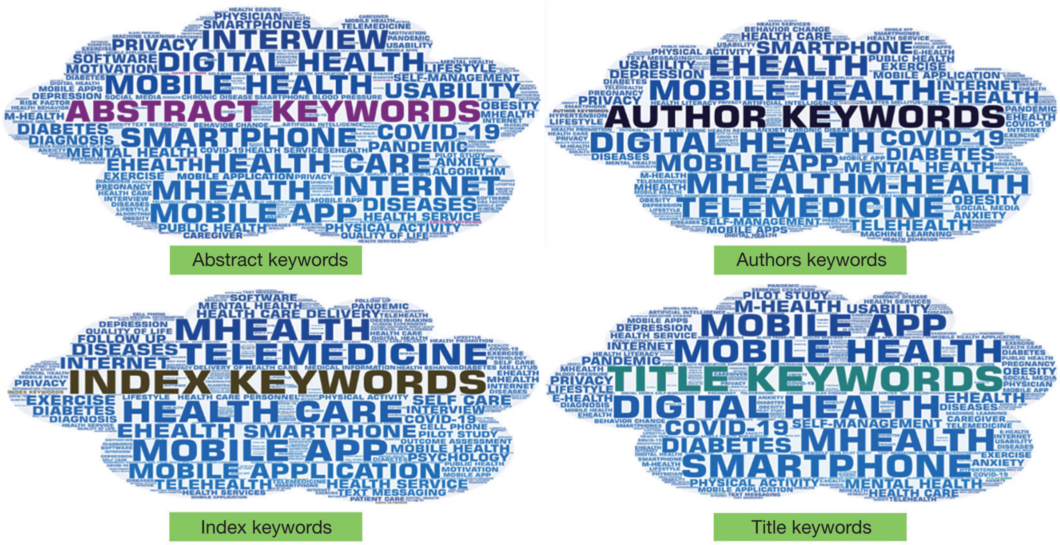

Figure 8 Illustration of the famous author, title, abstract, and index keywords used in mobile health publications.

increase in the citation levels since 2003.

Furthermore, the results also indicate that most of the published literature originated from the developed countries. These include the USA, Canada, the UK, and Australia. This trend undoubtedly indicates that the many publications from the developing world and low- and middle-income countries (LMICs) remain relatively low and less impactful or cited in comparison (1,2). This also concurs with recent findings of lesser-impacted studies of m-Health interventions from these countries (20).

The results also show that multiple authorships were indicators of collaborative work and research in this area. Most (94%) of the publications analyzed were from various authors. The top authorship lists from this study were from the lists compiled in earlier bibliometric studies (38-41). This can be attributed to the limitations and the analytical approach used in these studies, as discussed earlier in this paper. For example, this study analyzed a total of 37,470 (20,703 from Scopus and 16,767 from PubMed) publications, compared to 5,465 and 2,704 cited in the earlier bibliometric studies (38,39).

It is also important to note that there was a considerable increase in the total number of publications and their impact levels in recent years (2020–2022).

The analysis results from this review indicate that the origin and the earliest publications in this area can be attributed to the original work cited in this area (3,10). These seminal publications predate any of the published work from all subsequent publications and published reports recorded by all the authors and institutions searched in this study and from the previous lists of the most prolific authors compiled from other bibliometric studies. Furthermore, these results indicate that the highly cited authors, countries, and institutions publishing in the m-Health area mainly originate from the developed world. The absence of impactful publications from the developing world and LMICs remain subject to further work. These findings sharply contrast with the perception of these countries' increased publications and interest in m-Health in the last decade (1). These publications were supported by many of the world's global health and telecommunications bodies and industry conglomerates, such as the WHO, International Telecommunication Union (ITU), m-Health alliances, and others (2). Nevertheless, the impact level, discussions, and limited upscaling of the numerous publications originating from the LIMC countries to further research.

As discussed earlier, the search methodology followed in this study was based on identifying essential factors that can influence the results of a bibliometric study in this area: namely, the accurate choice of the most appropriate, more comprehensive, and relevant database, the broad and precise selection of the search keywords used, and the citation metrics used.

Compared to earlier studies, the differences concluded from the results of this study can be mainly attributed to the above factors. For example, the choice of WoS database in (39) had limited retrieved records to 2,704, compared to the much higher records retrieved in this study. While the selection of search keywords was broadened in the bibliometric research (39), compared to the earlier study (38), some of these were irrelevant to m-Health, such as 'mobile health unit', 'mobile unit', 'tablet computer', 'mobile device' (39). As discussed earlier, these keywords were excluded in the current study as inaccurate and invalid representations of m-Health. Although the Scopus database was used in the study (38), the following search mechanism was based on a single keyword 'mobile health/m-Health'. These and other limitations can render some of the outcomes and subsequent results from these studies contestable. These and other limitations highlight the need for more robust approaches to consider the above issues and accurately identify keywords and search methodology.

Regardless of these differences, some relative similarities were obtained from this study compared to the earlier studies cited on their lists, such as those of most prolific institutions. As shown in *Table 1*, the top five countries remain the same, with minor position changes in the present and previous studies. These were the USA, the UK, Australia, Germany and Canada.

These results also reconfirmed the publishing lead of the US institutions. However, the results from this study showed the inclusion of two UK institutions (University of Oxford and University College, London) in the current list; these institutions were not included in either of the earlier studies (38,39). This inclusion indicates the increasing trend of publications and research from the UK in recent years.

From the top publishing journals' perspective, the *Journal of Medical Internet Research* (*JMIR*) and its sister journals (*JMIR Mhealth Uhealth*) remain unchanged and concur with the results from a recent bibliometric study (41) in terms of the domination of *JMIR* family of the top publishing journals with the *JMIR Formative Research* replacing the *JMIR Protocols* (in both Scopus and PubMed) as the 3 top journals with respect to number of publications. The variations in the top publishing journals indicate increasing competition among the leading and specialist journals. Also, there is diversification of the m-Health themes being published in these journals, compared to the others not on the list.

As shown in *Figure 8*, there is a noticeable increase in the usage of the term 'digital health' in conjunction with m-Health publications. In recent years, some high-impact specialist journals were launched, such as the *Lancet*'s *Digital Health* and *Nature*'s *NPJ Digital Medicine*, that have since been increasingly publishing different m-Health application areas. This interchange of these terms will probably impact future citations of 'mobile health or m-Health' literature research. However, the rapprochement between the two terms remains unclear and ambiguous, leading to increased fuzziness on how m-Health relates to digital health (2). These issues require further work from bibliometric and ontological perspectives (2) and on the many 'known unknowns', including the correlation between m-Health and digital health (2). The gap between the published literature from the developed world compared to LMICs and developing countries can be attributed to many challenges. These include, for example, lack of funding, appropriate technical and clinical knowledge base, infrastructure, upscaling, and successful large-scale deployments of m-Health (digital health) systems in these settings.

Finally, the introduction of smartphone-based m-Health Apps has effectively evolved the area into two separate and de facto disciplines: market-driven m-Health Apps and the science of the m-Health domain. While the former is massively successful, the latter is still 'under the radar' from clinical, cost-effectiveness, efficacy, health policy, and global acceptability perspectives. These critical issues necessitate further studies that address the scientific aspects of m-Health more clearly and, beyond that, the basic understanding of m-Health in the smartphone-based Apps domain. Further work on a deeper understanding of the science of m-Health is also required to better encapsulate these scientific and technological principles of m-Health beyond the existing box of the smartphone-centric models and their 'm-Health Apps' market-driven ecosystems.

Limitations and future research directions

This study has the following limitations. First, it relied solely on data from Scopus and PubMed, limiting its scope to English-language publications and excluding conference abstracts. While this exclusion does not significantly impact the overall results, the data could have missed some relevant non-English publications since it is estimated that 90% of the publications in this area are in English. The Scopus and PubMed were selected as these provide broader coverage in health-related fields compared to other databases like WoS used in some earlier studies.

This limitation necessitates future studies to include non-English literature, alternative collaboration metrics, adding more content analysis, and focusing on specific m-Health Apps published in non-English languages.

Moreover, the COVID-19 pandemic has boosted the m-Health research, studies and publications in recent years, particularly from epidemiological, mental health, diagnostic, and infection mointoring perspectives using m-Health Apps developed for these and other Apps. However, the impact of these recent publications from the bibliometric perspective are unlikely to change the key patterns of the publication data presented.

The other limitation of this study is in the co-authorship criteria used. This criterion might affect the data captured on the research collaboration patterns as presented in this paper. This can be due to the potential biases in the author's indexing process acquired from the databases. Future studies to explore alternative metrics that can present more accurate collaboration analysis and visualization patterns can be considered to mitigate this bias limitation.

Finally, this study did not detail into the specific publications' content analysis, clinical data, or qualitative assessments. It also did not explore the specific m-Health application areas beyond the search keywords. These are beyond the scope of any bibliomtric study and are subject for future specific literature review research.

From the future research perspective, the increasing volume of m-Health publications focusing on exculsively on the smartphone Apps remain the dominating trend in this area, and is expected to continue in the foreseeable future. However, there is relatively new trend that these publications are increasingly grouped under the umbrella terms 'digital health' or 'digital health applications'. The evolving relationship between 'digital health' and 'm-Health' remains unclear, with blurring boundaries between 'digital health' and 'm-Health'. These issues remain largely ambigious and not widely studied or clearly understood. A concise understanding of this correlation requires further bibliometric research and studies in this particular niche yet important area.

Conclusions

This paper presents a comprehensive bibliometric study on m-Health from 1997 to 2023. The analysis provided the definitive literature evidence and historical insights into the origin, seminal publications, prolific authors, top publishing journals, leading countries, and collaborating research institutions in this area. It also identified the recent trends in the collaboration patterns and authorship dynamics, notably influenced by the surge in publications following the COVID-19 pandemic.

The study highlighted that the USA remains the country with the most country in m-Health research and publications, followed by the UK, Australia, Germany, and Canada. The top publishing journals in this area remain the *Journal of Medical Internet Research* (*JMIR*) and its affiliated journals (*JMIR Mhealth Uhealth*, *Journal of Medical Internet Research*, *JMIR Formative Research*). These journals maintained their prominence in this area, exhibiting high citation impact factors.

However, the results also underscored a significant lack of highly cited publications from the developing and LMICs, highlighting a disparity in highly impactful and research output from these countries. Bridging this gap requires concerted global efforts and further research on the causes of this disparity in the m-Health literature in these countries. Moreover, the study acknowledged its limitations and highlighting the emerging trend of grouping the m-Health publications under the umbrella term of 'digital health'. This can potentially reshape the terminology landscape and warrant further research and bibliometric studies to understand its implications on the relevant literature citation and terminological shifts.

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Footnote

Peer Review File: Available at https://mhealth.amegroups.com/article/view/10.21037/mhealth-23-20/prf

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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