A Bibliometric Analysis of Female Technology (Femtech) Research: Trends and Gaps from 2013 to 2023

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Abstract

Gender health remains an unfinished issue worldwide. As the critical intersection of females' health and technologies, Femtech emerged beyond a niche market and disrupting conventional healthcare practices for women. Given the various interest and research outputs continue to mushroom on females' health, a retrospective view on this dynamic field is essential. This research aims to examine Femtech global research landscape using bibliometric analysis technique. Following PRISMA flow diagram, Femtech publications published between 2013 and 2023 in Scopus database were systematically analyzed. A total of 183 publications covering 21 subject areas, in 6 languages from 44 countries were identified for this purpose. The outcomes indicate these publications were predominantly in the field of medicine rather than information technology and a majority were monopolized by authors, journals and sponsors from developed nations. Initial keywords review found to accentuate "mhealth"; "pregnancy"; "mobile applications"; "women's health", however, "telehealth"; "wearables"; "privacy"; "reproductive health"; "menopause" had also drawn high interest. The research contributes methodically by applying bibliographic analysis to understand Femtech research trends and assess citations as measure impact on Femtech research ecosystem. This research provides a blueprint empowering researchers, practitioners, investors, Femtech industry players and stakeholders to collaborate in Femtech research to enhance adoption of Femtech globally.

Keywords: Femtech; digital health; female technology; women health; bibliometric analysis

Submitted: October 6, 2024 / Approved: December 26, 2024

Introduction

"Femtech" was coined by Ida Tin in 2016 (Tin, 2016). It is defined as a plethora of tech-driven medical and healthcare software, products and services specifically tailored to cater diverse female's health needs (Almeida, Balaam & Comber, 2020; Tin, 2016). These gendered solutions consider cisgender women, lesbian, gay, bisexual, transgender, queer, or questioning and other (LGBTQ+ communities), health institutions, fertility clinics and diagnostic centers as target users. Femtech harnesses an array of innovation encompassing computer vision, artificial intelligence (AI), machine learning (ML), internet of things (IoT), big data analytics, blockchain technology, cloud computing, virtual reality (VR), augmented reality (AR), robotics and others to seamlessly address conditions that solely, disproportionately or differently affecting females across lifespan (e.g. menstruation, pregnancy, gynecologic cancers, osteoporosis, cardiovascular diseases) (Dokras, 2022; Barreto et al., 2021; Femtech Analytics, 2021). Period trackers, fertility bracelets, pregnancy contraction digital sensor, digital breast pumps, smart bras and menopause apps are a fraction of diverse Femtech.

The emergence of Femtech has revolutionized the landscape of female's healthcare delivery and experiences (Somera, Mendez & Mummert, 2020; Mutsai & Coleman, 2019). It serves as a viable alternative to bridge health disparities, promote self-empowerment, improve health and life outcomes among females (Guo, Liu & Prester, 2023; Urquijo & Belloso, 2023; Mehrnezhad et al., 2022; Gkrozou et al., 2019; Fitzpatrick & Thakor, 2019). In 2021, the global Femtech market was valued approximately USD 51 billion and was projected to hit USD 103 billion by 2030 trailing at 8.1% compound annual growth rate (CAGR) 2022-2030 (Stewart, 2022). The growth has been intertwined with a series of factors including the prevalence of female's health issues, positive societal shift to destigmatized topics about female's health, motivation of feminist human-computer interaction (HCI), influx investments, and advanced technologies (McMillan, 2023; Alexander et al., 2020; Hillyer, 2020; Keyes et al., 2020; Tingen, Halvorson & Bianchi, 2020; Fitzpatrick & Thakor, 2019). The recent outbreak of global health crisis such as Coronavirus pandemic 2019 (COVID-19) and increasing awareness and demands on personalized health solutions have further catalyzed the pace of Femtech evolution (Figueiredo et al., 2024; Atkinson et al., 2023; Hod et al., 2023; Milcent & Zbiri, 2023).

Following the introduction, the remainder of the paper is structured as follows. Section 2 provides a comprehensive review of existing literature relevant to the topic. Section 3 introduces the methodological procedure employed in this research. Section 4 analyzes the dataset and discusses the results. The final section encapsulates primary research findings and highlights implications arise from the study, and research limitations suggested possibilities for future research.

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Literature Review

While making remarkable progress, Femtech is still an emerging technology. It is in the development phase where most materials and information are white papers and technical reports generated by manufacturers and stakeholders vested investment (Halaweh, 2013). Researchers attempted to advance knowledge and scientific rigor on Femtech through scoping review (Fiská et al., 2023; Karim & Talhouk, 2021; Earle et al., 2020), narrative review (Warty et al., 2023; Hughson et al., 2018), thematic analysis (Patel et al., 2024; Hohmann-Marriott, 2023; Nellore & Zimmer, 2023; Musgrave et al., 2020), systematic review (Paripoorani et al., 2023), meta-analysis (Liu et al., 2022) and literature review (Haryanti et al., 2023). Nonetheless, these views were restricted to specific types of Femtech (i.e. Apps, telehealth, telemedicine) or medical field (i.e. menstruation, pregnancy, menopause, cancer).

A synthesis on Femtech related research would provide a deep understanding on the overall research trends and possibly gaps for future Femtech research. Particularly, advancement of information technologies and Internet in last decade plus recent Covid-19 health crisis induced an explosive surge in science and clinical medicine publications (Cheng et al., 2024; Hu et al., 2024). The rapidly grow scientific publications and new databases overwhelmed researchers and practitioners to effectively manage the knowledge and information. The conventional literature review depends on manual screening and organization of knowledge proven inadequate for these respective parties keep up to date with new breakthroughs, emerging trends and research hotspots (Cheng et al., 2024). The bibliometric analysis method is a beneficial approach. It applies mathematical and statistical tools to evaluate the interrelationships and impacts of publications, authors, institutions and countries in a specific research area. It enabled researchers to capture historical knowledge and monitor the present research landscape of a particular field (Lawani, 1981). The applications of quantitative analysis, graphical representations and visualizations in bibliographic approach appear to be more intuitive and rigorous in providing comprehensive view (Wang et al., 2021).

Bibliometric analysis was first introduced by Pritchard has long and rich history over a century (see Broadus, 1987; Lawani, 1981). Cole and Eales (1917), Hulme (1923) and Lotka (1926) were among researchers who made the early attempts shaping the knowledge and development of bibliometric approach. In earlier periods, most bibliometric analysis primarily concentrated on author and citation metrics (Price, 1965). As complex scientific communications and knowledge increasingly challenge researchers' understanding, advanced approaches are needed to navigate the research landscape. Bibliometric studies revolve facilitating visualization and network analysis on the types of collaborations, countries involved, topics and other information burgeoning interest. In recent time, this approach is widely applied in multidisciplinary research such as Fintech (Aysan & Nanaeva, 2022), health technologies (Luo et al., 2022; Ali et al., 2021), women studies (Liu et al., 2023; Hassan et al., 2022; Cardella, Hernández-Sánchez & Sánchez-García, 2020). However, bibliometric analysis on Femtech had received limited attention among researchers.

With the increasing global focus on women's empowerment and health, researchers have bibliometrically analyzed various relevant research fields. For instances, the topics of women's reproductive health rights (Farizi, 2024), obesity women with cancer (Gu et al., 2024), postmenopausal women's psychological health (Kalra et al., 2023), ovarian cancer (Cardella et al., 2020), fear of childbirth (Dai et al., 2020), health inequalities (Cash-Gibson et al., 2018), female genital mutilation (Sweileh, 2016) and others. The main goal behind these literature was to solve issues impacting women's health, wellness and self-empowerment in different contexts with evidence generated via the bibliometric tools.

Femtech is a disruptive technology that enables a more inclusive and equal society specifically for women. Yet, few bibliometric studies have examined this topic. For example, Mulyani et al. (2024), Sibanda, Ndayizigamiye and Twinomurinzi (2024) analyzed the use of Industry 4.0 technologies and digital communication media in maternal care using this approach. While Ramasamy et al. (2024) provide bibliometric evidence on the role of digital technologies on women's empowerment and entrepreneurial activity. Foreseeing the temporal focus of digital health industry moving toward key themes of "AI", "patient empowerment" (Hu et al., 2024), and increasing interest in gender-based bibliometric studies (Sebo et al., 2024) . This research is timely and essential.

This paper endeavored to assess the global research landscape on Femtech, therefore, the proposed research objectives are to examine: (a) Frequency and trends on Femtech publications, (b) Common keywords used, research hotspots and frontiers (c) Key contributors, (d) Publication impact in the field of Femtech, and (e) Scholarly collaboration patterns.

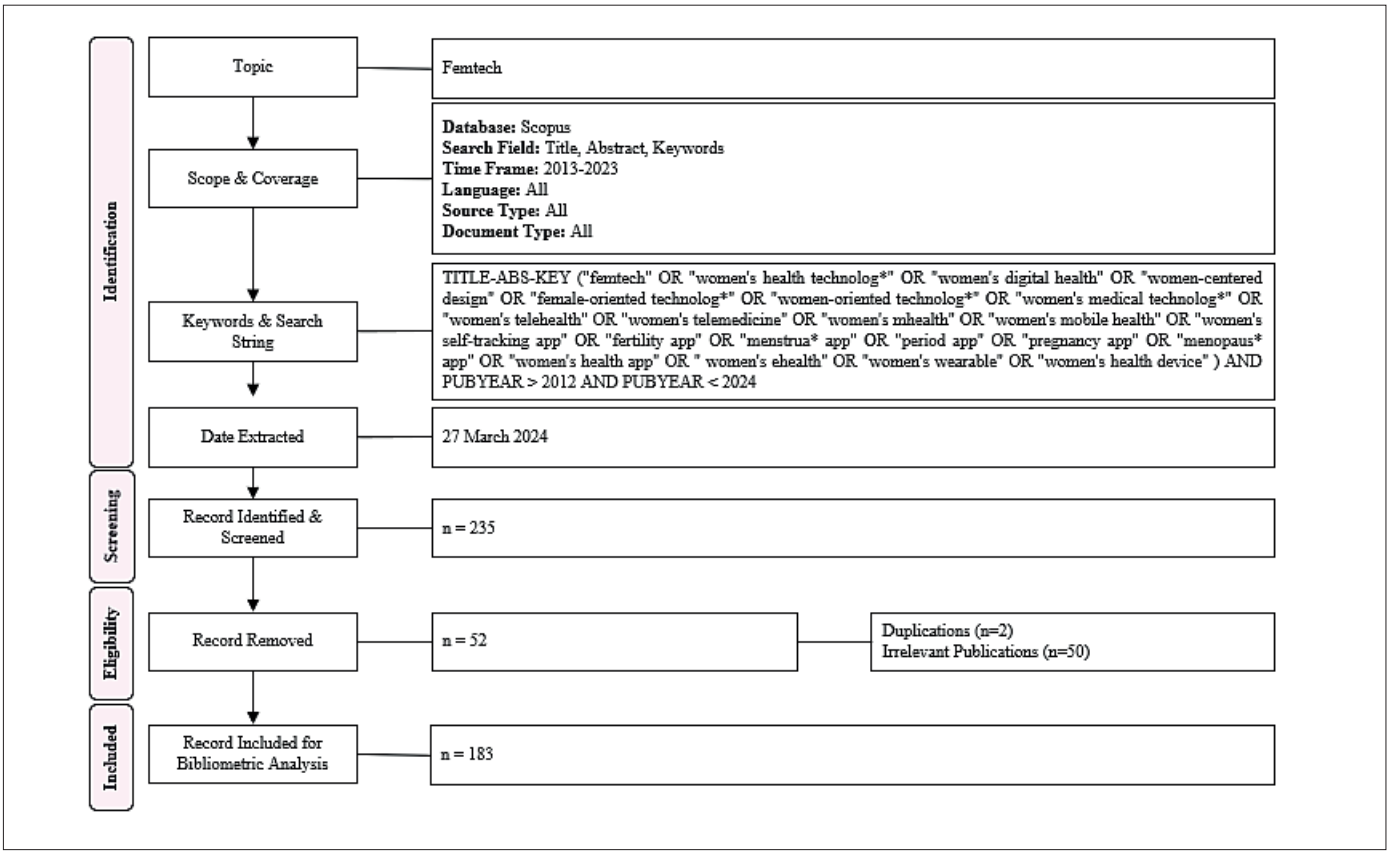
Methodology

Applying bibliometric analysis approach, this research retrieved data from Scopus database. The database consists of more than 94 million multidisciplinary documents updated daily from about 7,000 international publishers and over 2.4 billion cited references (Elsevier, 2024). It is a robust and reliable data source extensively used to analyze bibliographic data (Hassan et al., 2022; Singh et al., 2021; Baas et al., 2020; Zhu & Liu, 2020, Li et al., 2010). Moher et al. (2009) PRISMA flow diagram was adapted for this research (see Figure 1). This research focuses specifically on publications pertaining to Femtech within 2013 to 2023 as inclusion criteria. This timeframe reflects the most relevant trends and advancement of Femtech field. Although the terminology of Femtech was popularized in 2016, the concepts began to gain traction around 2013. The first menstruation fertility tracking mobile apps became available the same year marking Femtech initial emergence (Femtech Analytics, 2021). Setting a broad timeframe could include less relevant publications which risks diluting the focus and deriving bias conclusions. Parenthetically, bibliometric analysis involves reviewing abundance documents and setting a specific timeframe ensures the methodological soundness.

Data collection

The flow of data collection from initial search to final selection studies inclusion was outlined in Figure 1. The search field includes the "title", "abstract" and "keywords" in the Scopus database. All keywords were meticulously selected to be included into the research topic. The Boolean operator of "OR" and asterisk (*) were utilized to expand the search and address the potential suffixes variations. The title and abstract of records were screened for any duplications to be eligible and included in further analysis. Full-text review was conducted where there were absence of abstracts or insufficient details. The output of the search string captured 235 records encompassing research in qualitative, quantitative and mixed-method paradigms. Of these, 52 records were excluded due to duplications and not related to Femtech. Finally, a total of 183 records were eligible for analysis.

Figure 1. PRISMA flow diagram



Source: Adapted from Moher et al. (2009)

Data analysis tools

Scopus analytical, software of VOSviewer 1.6.19 (Nees Jan van Eck and Ludo Waltman) and Harzing's Publish or Perish 8.9.4538 (Tarma software Research Ltd) were used in data interpretation and visualizations mapping. The robust analytics powered by Scopus analyzed and synthesized the search results. Whilst VOSviewer visualizes the set of bibliographic data. Its map creation and clustering technique allows researchers to quickly visualize how the authors, topics, publications or sources are connected. Jointly, Harzing's Publish or Perish retrieves information on academic citations. The metrics allow researchers to assess their scholarly work's influence and its reception within this field. These software are popular among researchers in establishing bibliometric analysis (Liu et al., 2023; Lam et al., 2022).

The process of analysis began with the download of software from open-source networks. The bibliometric data of 183 records obtained from Scopus database were exported in Microsoft Excel CSV and RIS formats compatible with software. The CSV file was uploaded in VOSviewer to construct the bibliometric maps. The data used for content analyses included the co-occurrence and cluster network of research keywords, authors, countries, sources and documents. Parameters or number of occurrences were set to filter noises that could potentially skew the output. The Java-based algorithms process and extract relevant data needed for generating the graphic representation. Whereas the RIS file was imported into Harzing's Publish or Perish for analysis purpose. The bibliometric records form the foundation for the software to automatically calculate citation metrics and identify highly cited publications. It encodes authors' academic contributions and research impacts within this timeframe.

Results and Discussion

Core Information of Femtech Publications 2013-2023

Of 183 Femtech publications, a large cohort was Article (n=124), followed by Conference Paper (n= 22), Review Article (n=22) and others. Based on the metrics, 77.60 were single-authored publications without any collaboration. In this sense, 3.76 authors could have jointly produced a document. Collectively, there were 1,877 citations received, averaging 170.64 citations per annum with 10.26 citations per publication. The overall h-index and g-index were 22 and 37 respectively. The authors can achieve the h-index by securing at least 22 publications and citations. Assuming the academic community has published at least top 37 publications, a total of 1,369 citations is within reach. The detailed information is shown in Table 1.

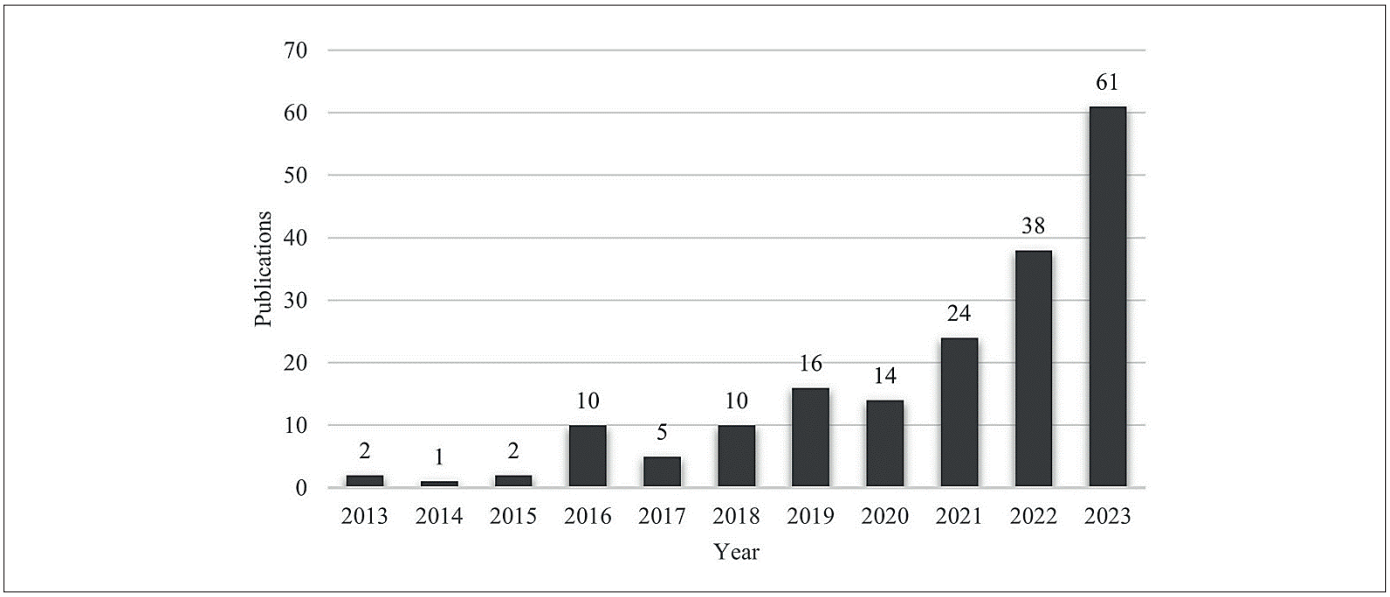
Table 1. Core information of the dataset

Details	Outcomes
Publication years	2013-2023
Publications	183
Types of publications	
Article	124 (67.76%)
Conference paper	22 (12.02%)
Review	22 (12.02%)
Book chapter	5 (2.73%)
Editorial	4 (2.19%)
Book	2 (1.09%)
Note	2 (1.09%)
Short survey	2 (1.09%)
Citation years	11 (2013-2024)
Citations	1,877
Citations per year	170.64
Authors per publication	3.76
Single-authored publications	77.60
h-index	22
g-index	37

Frequency and Trends on Femtech Publications

Figure 2 presented the frequency of Femtech publications between the period of 2013 to 2023. The minimum number of publications recorded in 2014 is one (n=1). However, from year 2020, the annual publications witnessed a steep rise and achieved the highest number of publications after three years. Albeit there have been fluctuations, the number of publications from the inception in 2013 were two (n=2), increased to sixty-one (n=61) in year 2023. This implies research interest in Femtech had proliferated and increased important. The trends reflect the evolving awareness surrounding gender health and funding or support for research initiatives.

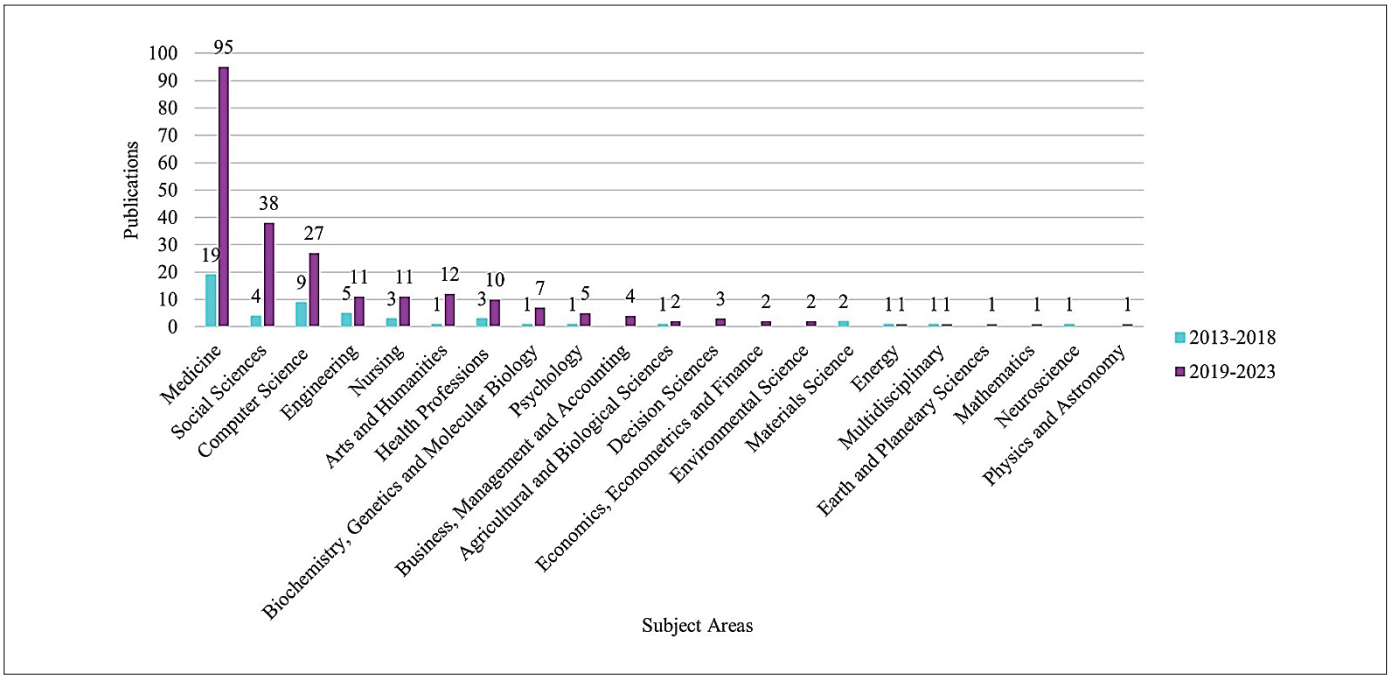
Figure 2. Frequency of publications on Femtech 2013-2023



Subject areas

The subject of Femtech has pervaded vast fields (see Figure 3), peculiarly in Medicine (n=114), Social Sciences (n=42), Computer Science (n=36) and Engineering (n=16). The trends reflecting scholarly attention have been skewed to health focused. However, from year 2019 to 2023, had witnessed continuous expansion and diversification of research in Femtech. Researchers from the field of Business, Management and Accounting; Decision Sciences; Econometrics and Finance; Environmental Science; Earth and Planetary Sciences; Mathematics; Physics and Astronomy had contributed to increase in number of Femtech related publications. Conversely, there was a reduced interest in Materials Science and Neuroscience. The underlying reasons underpin these dynamics could be the shift of funding priorities, researchers pursuing other trending areas, changes in policies and societal needs (Reihl et al., 2022; Talebian et al., 2021; Himanen et al., 2019).

Figure 3. Classification of subject areas (a publication can be classified into more than one subject area)



Language of publications

The Femtech publications were published in 6 different languages, comprising English 93.05% (n=174), German 3.74% (n=7), Italian 1.60% (n=3), and each in French, Japanese and Spanish (n=1, 0.53%). A total of 4 publications were published in dual languages. The predominance of English language not merely a coincidence but rather an interplay of historical legacies and journal internationalization on this topic. English language has been propagated worldwide through the British colonization and evolved as global lingua franca. Academic practices and cross-border collaboration further solidifies the role of English as a bridge connecting scientific communities and broad audience from diverse linguistic backgrounds.

Common Keywords Used, Research Hotspots And Frontiers

Keywords analyses were conducted to identify the key foci, trends and frontiers of Femtech research. The data for analyses were extracted from Femtech publications titles, abstracts, index keywords and author keywords. Data cleansing was initially performed on keywords with multiple presentations or variations (e.g. "app" and "apps") to bypass fragmentation and dilution of data that would skew the final results. Analysis of "all keywords" highlighted keywords namely "humans"; "female"; "pregnancy"; "mobile applications"; "article"; "adult"; "mhealth"; "femtech"; "telemedicine"; "women's health" were the top 10 frequently utilized words, phrases or concepts in Femtech publications (see Figure 4a). The keywords density reveals Femtech space has primarily targeted adults females. Across the category, pregnant women have been the focal point. Consumers from young females, adolescent and middle-old aged segments received less attention. These gaps provide opportunities for future Femtech research and innovation.

Simultaneously, "author keywords" (n=603) were further analyzed to gain in-depth and specific insights into the main content and core focus of Femtech authors. A total of 26 nodes (keywords) have been identified to appear more than 5 times in multiple publications, were accrued with 159 links and total link strength (TLS) of 391. According to Van Eck and Waltman (2017), TLS quantifies the frequency and relevance of keywords co-occurrence in publications. The networks were mapped to visualize the significance of the nodes (see Figure 4b). The nodes in

larger size signified high frequency of co-occurrence and the thickness of connections showed stronger TLS. In the light of co-citations, co-occurrence or common characteristics, the densely interconnected keywords were automatically grouped and arranged into a similar cluster.

The results revealed underlying intricate structures and emergence of distinct themes. "mhealth", "pregnancy", "femtech", "mobile applications", "women's health" were closely related and have been central to discussion on Femtech. The pattern could be many studies investigating the integration of mobile apps, mobile health and women-oriented technologies in existing healthcare systems to address women's specific health needs in order to improve their wellbeing (e.g. Dixon et al., 2023, Hohmann-Marriott, Williams & Girling, 2023; Nissen et al., 2023). Figure 4c detailed the periodical development of research hotspots. The darker colour nodes in purple or blue pinpoint topics have been discussed earlier, in contrast, those in green and yellow were recently of high interest and new frontiers. It annotated that at the end of 2022, "Femtech" is still drawing Femtech researchers' attention. However, the research foci visibly shifting towards "telehealth"; "wearables"; "privacy"; "reproductive health"; "menopause". Based on Figure 4, a summary of the keywords, clusters and research themes is tabulated in Table 2.

Figure 4a. Density visualization of co-occurrence analysis on all keywords

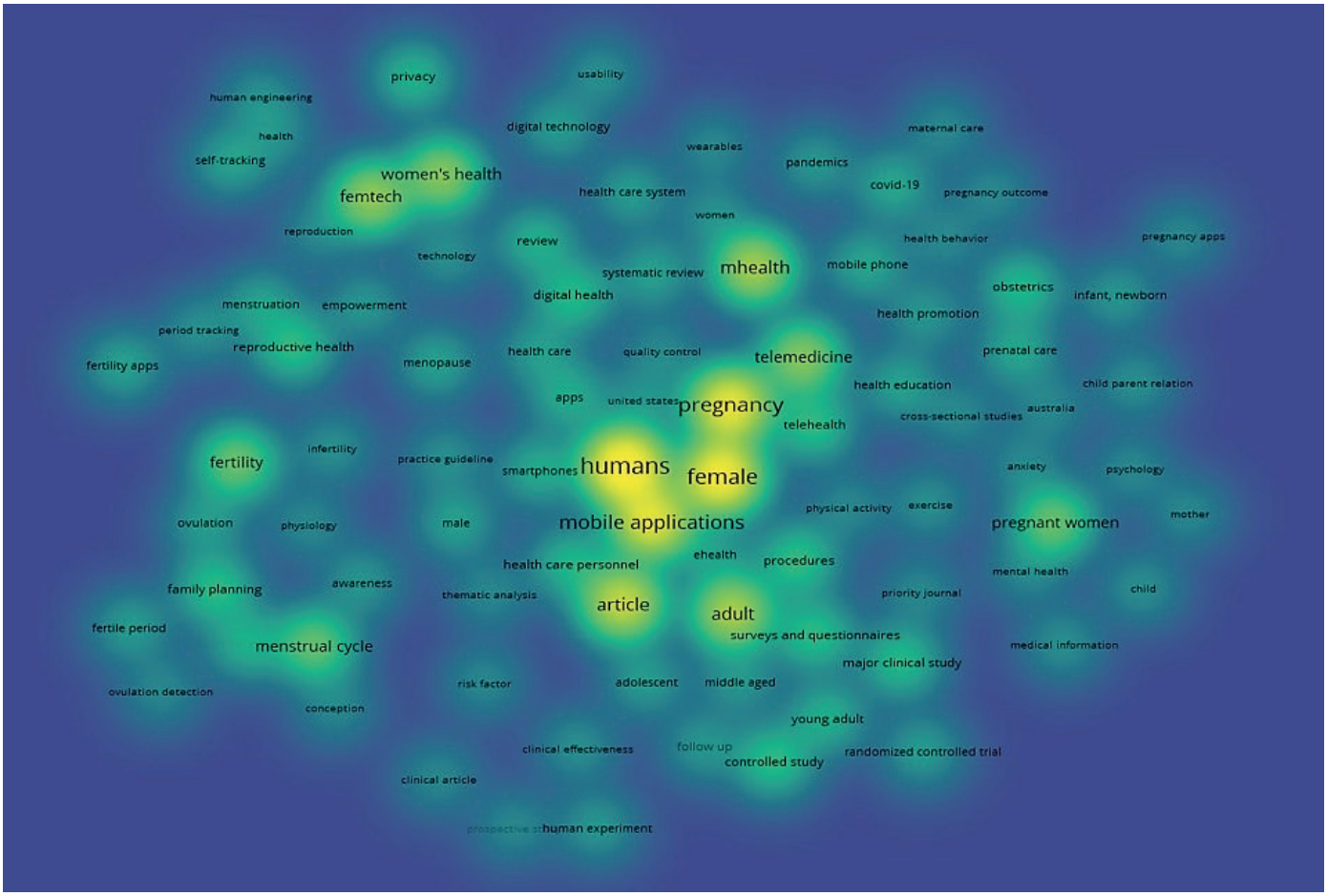


Figure 4b. Network visualization of co-occurrence analysis on author keywords

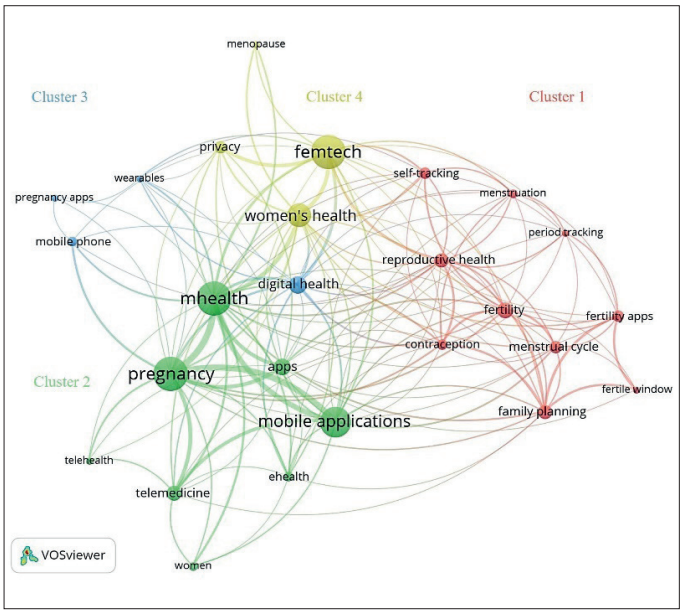


Figure 4c. Overlay visualization of co-occurrence analysis on author keywords

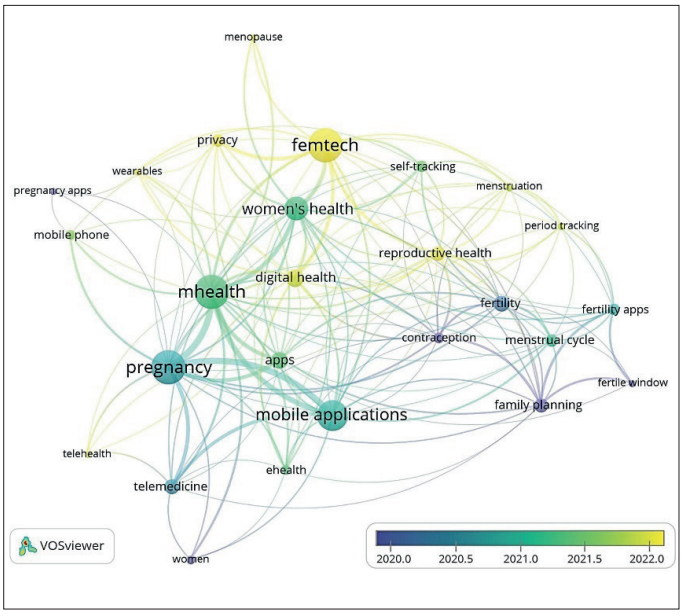


Table 2. Summary of keyword analysis

Cluster	**Keywords**	n	TLS	**Research Theme Areas**
1 Red	fertility	13	32	Promote digital contraception and fertility awareness; Development of predictive analytics and biomedicalization to empower women in self-care
	family planning	11	34	
	reproductive health	11	36	
	menstrual cycle	10	22	
	fertility apps	9	22	
	self-tracking	9	20	
	contraception	8	32	
	menstruation	6	16	
	period tracking	5	12	
	fertile window	5	11	
2 Green	mhealth	36	95	Digitized and datafied medical and healthcare delivery; Trends of remote monitoring during and post Covid-19 pandemics; Improve clinical decision supports with innovations; Perceptions, acceptance and utilizations of personalized health intervention
	pregnancy	36	81	
	mobile applications	32	63	
	apps	14	35	
	telemedicine	12	31	
	ehealth	7	19	
	women	6	11	
	telehealth	5	8	
3 Blue	digital health	15	41	Transformation of pregnancy and nursing management; Sources of health information for education, early diagnosis and supports; Prevalence of virtual assistance, wearable sensors and mobile apps for health guidance
	mobile phone	7	11	
	wearables	5	13	
	pregnancy apps	5	4	
4 Gold	femtech	36	95	Feminist human computer interaction; women centric design; Alleviation of taboo stigma and gender disparities in health; Review data security privacy protection, ethics, policy and regulations; Treatment for issues of menopause and osteoporosis
	women's health	22	53	
	privacy	10	19	
	menopause	5	8	

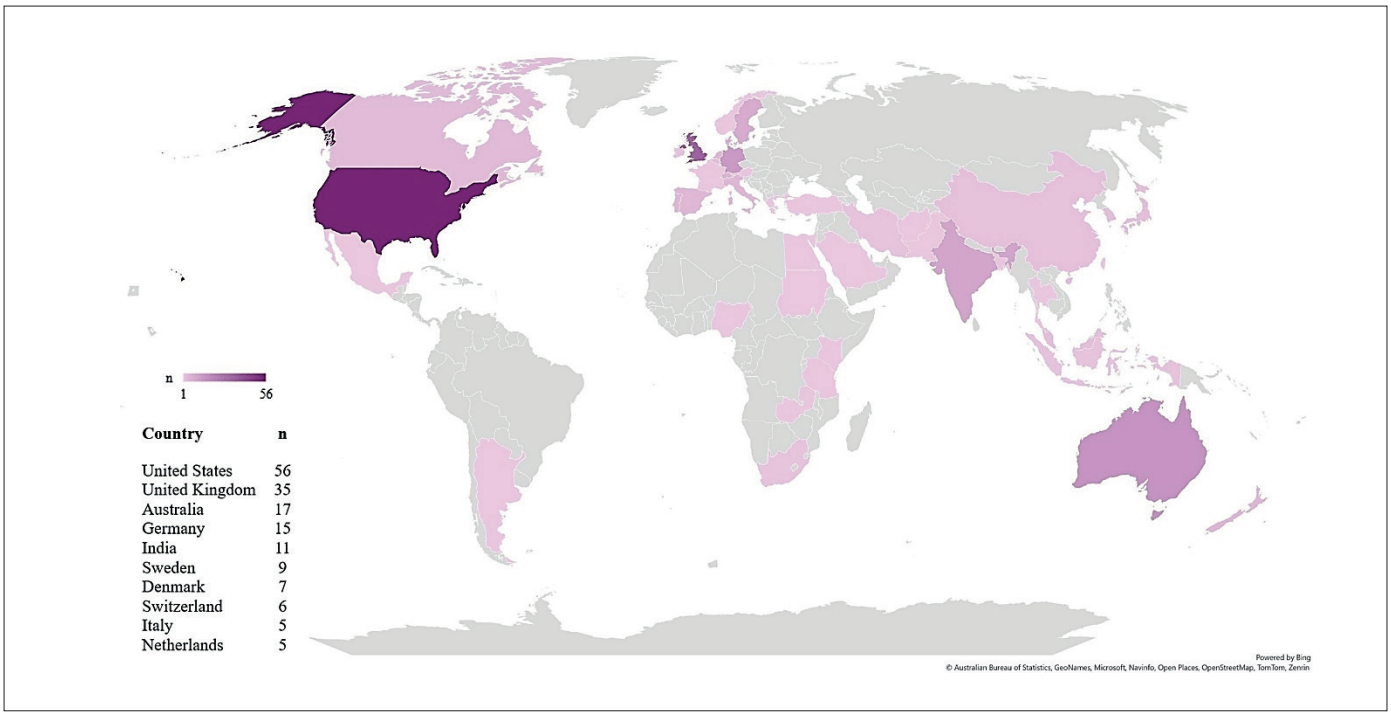
Note: n=frequency of publications, TLS=total link strength

Key Contributors

Most productive countries

The leading country publishing about Femtech was the United States (n=56), followed by the United Kingdom (n=35), Australia (n=17), Italy and Netherlands (n=5) were at the bottom of the table. Likewise, publications from the Non-Western countries remain scarce. Revisiting existing publications, the outcomes possibly relevant to the novelty of Femtech and myriad obstacles bound by socio-cultural differences, health's decision-making power and open-mindedness towards female's bodies and health topics (Hatim et al., 2021; Hamid & Fallon, 2020; Yazdany et al., 2020; Singer & Bowman, 2002). These outputs concur with the viewpoint that centrum for women's studies were mainly conducted in Western countries (Hassan et al., 2022; Tsay & Li, 2017). A noticeable fact is less extent publications from numerous countries ranked higher for gender equality, such as Ireland (n=2) and Norway (n=1). Despite the number of publications published in a small number of countries, there was evidence that Femtech has gained momentum globally (see Figure 5). The intensity of colour across the map represent the numbers of publication. Areas with higher levels of academic activity were shaded in darker colour. It suggests that these areas have robust institutional support, investments and active research communities specialized in females' health and related technologies. Conversely, the brighter areas has fewer publications, indicating new opportunities for upcoming studies.

Figure 5. Geographical distribution of publications about Femtech between 2013 and 2023



Main affiliations and funding sponsors

Of Femtech publications from 160 universities and institutions, a majority of researchers were affiliated to "Georgetown University" and "The University of Utah". Both institutions recorded more than 5 publications and leading others such as "University of Pittsburgh School of Medicine", "University of Utah School of Medicine" and "Universitätsklinikum Düsseldorf". This implied that a significant number of publications were from Central Europe region, Northeastern and Western regions of the United States. Besides, the Femtech publications in Scopus database were mainly funded by "National Institutes of Health", "Engineering and Physical Sciences Research Council", "National Center for Advancing Translational Sciences", "U.S. Department of Health and Human Services" and "United States Agency for International Development".

Most active source

Table 3 provides publication sources for Femtech research. "JMIR Mhealth and Uhealth" was the key journal (n=10; Impact Factor=5.0; CiteScore 2022=10.9). This is followed by "ACM International Conference Proceeding Series" (n=6) was ranked 2nd. "Conference On Human Factors In Computing Systems Proceedings" with 5 publications has high impact and is notably influential within the Femtech research community (h-Index = 216).

Table 3. The most active source titles

No.	Source Title	n	h-Index	Country
1	JMIR Mhealth and Uhealth	10	84	Canada
2	ACM International Conference Proceeding Series	6	137	United States
3	Conference On Human Factors In Computing Systems Proceedings	5	216	United States
4	Biolaw Journal	4	6	Italy
5	JMIR Research Protocols	4	37	Canada
6	Journal of Medical Internet Research	4	178	Canada
7	BMC Women's Health	3	58	United Kingdom
8	Frontiers In Public Health	3	80	Switzerland
9	JMIR Formative Research	3	20	Canada
10	NPJ Digital Medicine	3	64	United Kingdom

Note: n=frequency of publications

Main authors

The list of most prolific authors who have contributed to Femtech publications was presented in Table 4. The dataset derived outstanding productivity from "Almeida, T." affiliated with Umeå Universitet, Sweden (n=6). Following that, "Baur, S.", "Freundl-Schütt, T.", "Strowitzki, T.", "Wallwiener, L.M." have separately produced 5 publications on Femtech and "Frank-Herrmann, P.", "Freis, A.", "Freundl, G.", "Krishnamurti, T.", "Mehrnezhad, M." each contributed to 4 publications. In the analysis, two facts that merit special attention were these authors were predominantly from Germany. In a similar vein, Strowitzki, T. has the highest h-Index (45). He has generated 492 research works between 1987-2024 and obtained 7,284 citations. The topical foci ranged from women's health, cancer diseases, male infertility, drugs research to tomography and others.

Table 4. The highly prolific authors

No.	Author	1st Publication	Status	TP	TC	h-Index	Countries
1	Almeida, T.	2014*	Active	28	360	10	Sweden
2	Baur, S.	1986**	2021	22	543	10	Germany
3	Freundl-Schütt, T.	2006**	2021	12	66	3	Germany
4	Strowitzki, T.	1987**	Active	492	7,284	45	Germany
5	Wallwiener, L.M.	2010**	2021	18	281	7	Germany
6	Frank-Herrmann, P.	1990**	Active	58	1,367	17	Germany
7	Freis, A.	2014*	2021	26	213	9	Germany
8	Freundl, G.	1978**	2020	119	2,032	21	Germany
9	Krishnamurti, T.	2008**	Active	57	984	17	United States
10	Mehrnezhad, M.	2015*	Active	33	240	9	United Kingdom

Note: *=first author, **=co-author, TP=total production, TC=total citation

Publication Impact In The Field of Femtech

In reviewing the Femtech publication impact, Lupton, D. and Pedersen, S. (2016) titled "An Australian survey of women's use of pregnancy and parenting apps" topped the list and has been cited 168 times (see Table 5). The overall outcomes showed studies in pregnancy and nursing management, menstruation health alongside the related apps have gained substantial recognition within the Femtech scientific community. Nonetheless, Hallam et al. (2022) opined females need beyond "bikini medicine" that primarily focused on the areas of gynecology and obstetrics health. It is essential to broaden the Femtech research dimensions towards contemporary health issues affecting women due to their changing roles.

Table 5. The highly cited publications

Document	Author	Year	Source	TC
An Australian survey of women's use of pregnancy and parenting apps	Lupton D. & Pedersen S.	2016	Women and Birth	168
Threats and thrills: pregnancy apps, risk and consumption.	Thomas G.M. & Lupton D.	2016	Risk and Society	93
The rise of pregnancy apps and the implications for culturally and linguistically diverse women: narrative review	Hughson J.A.P., Daly J.O., Woodward-Kron R., Hajek J. & Story D.	2018	JMIR mHealth and uHealth	79
The performance of fertility awareness-based method apps marketed to avoid pregnancy	Duane M., Contreras A., Jensen E.T. & White A.	2016	The Journal of the American Board of Family Medicine	74
Influence of mHealth interventions on gender relations in developing countries: a systematic literature review	Jennings L. & Gagliardi L.	2013	International Journal for Equity in Health	74
Smartphone medical applications for women's health: what is the evidence-base and feedback?	Derbyshire E. & Dancey D.	2013	JMIR mHealth and uHealth	71
Perceptions of patient engagement applications during pregnancy: A qualitative assessment of the patient's perspective	Goetz M., Müller M., Matthies L.M., Hansen J., Doster A., Szabo A., ... & Wallwiener S.	2017	International Journal of Telemedicine and Applications	66
Plausibility of menstrual cycle apps claiming to support conception	Freis A., Freundl-Schütt T., Wallwiener L.M., Baur S., Strowitzki T., Freundl G. & Frank-Herrmann P.	2018	Frontiers in Public Health	55
A review of pregnancy iPhone apps assessing their quality, inclusion of behaviour change techniques, and nutrition information	Brown H.M., Bucher T., Collins C.E. & Rollo M.E.	2019	Maternal & Child Nutrition	51
The Health-e Babies App for antenatal education: Feasibility for socially disadvantaged women	Dalton J.A., Rodger D., Wilmore M., Humphreys S., Skuse A., Roberts C.T. & Clifton V.L.	2018	PLoS ONE	50

Note: TC=total citation

Scholarly Collaboration Patterns

Co-citation analysis

Extending the view in the same vein, co-citation analysis measures the interconnectedness of relatively influential scholarly works (Small, 1973). The core premise infers the higher frequency of co-cited, indicates the stronger degree of relatedness or mutual influence of the contents. The co-citation structure surprisingly found that of 7,461 cited references, all the top 3 highly shared references were from Lupton, D. published between 2014 and 2015 (see Table 6). Both the citation and co-citation lists gauge the research inquiries and the line of thoughts that have emerged in Femtech. Researchers and others planning or newly entering this field can generate an initial reading list from these references to understand the seminal works, critical knowledge and concepts shaping the Femtech discourse. Sequentially, it builds a strong research foundation and prepares them for more comprehensive exploration.

Table 6. Highly co-cited references

Document	Author	Year	Source	TC
Apps as artefacts: Towards a critical perspective on mobile health and medical apps	Lupton D.	2014	Societies	6
Critical perspectives on digital health technologies	Lupton D.	2014	Sociology Compass	6
Quantified sex: a critical analysis of sexual and reproductive self-tracking using apps	Lupton D.	2015	Culture, Health & Sexuality	5
The digitally engaged patient: Self-monitoring and self-care in the digital health era	Lupton D.	2013	Social Theory & Health	5
Understanding the use of smartphone apps for health information among pregnant Chinese women: mixed methods study	Wang N., Deng Z., Wen L.M., Ding Y. & He G.	2019	JMIR mHealth and uHealth	5
Playing pregnancy: The ludification and gamification of expectant motherhood in smartphone apps	Lupton D. & Thomas G.M.	2015	Journal Media/Culture	4
Quantifying the body: monitoring and measuring health in the age of mHealth technologies	Lupton D.	2013	Critical Public Health	4
The quantified self	Lupton D.	2016	John Wiley & Sons	4
The use and value of digital media for information about pregnancy and early motherhood: a focus group study	Lupton D.	2016	BMC Pregnancy and Childbirth	4
Making parents: The ontological choreography of reproductive technologies.	Thompson C.	2005	MIT press	4

Note: TC=Total citation

Co-authorship analysis

The cooperation of countries and regions showed 13 countries have played a pivotal role in advancing the body of knowledge and fostering collaborations (see Figure 6a). As expected, United Kingdom and United States had the most extensive international collaborations and exchange of information. United Kingdom also has close collaboration in Femtech research with Australia, India, Portugal and Sweden. Whereas researchers in Italy, Spain and New Zealand concentrated on collaboration and expertise sharing within the local research community.

In total, 602 authors have published in Femtech related publications, but only 28 sets of co-authorships were identified. Authors with similar affiliations, overlaps study areas and close collaboration were allocated in a corresponding cluster. The most intensive cluster involved "Bailey, E."; Latendresse, G.; "Pentecost, R." and 17 other authors who jointly researched telehealth on maternal health and early parenting care. Alternatively, the most prolific author "Almeida, T." main co-authors such as Merhnezhad, M.; Shipp, L.; Toreini, E.; Balaam, M.; Comber, R.; Simpson, E.; Kuznetsov, S.; Hansen, L.L.; Catt, M.; D'Ignazio, C; Søndergaard M.L.J. have proactively researching the potential vulnerabilities and risks in data protection mechanisms of digital women's health. In general, all authors were split into 138 clusters, the top 18 clusters were marked (see Figure 6b). The bibliographic findings strongly conveyed research on Femtech domain was still in the early exploration stage and authors have concentrated on distinct research domains that do not overlap extensively. The largely isolated nodes reaffirm current collaborative connections or joint publications among the authors were relatively weak. The trend entailed authors actively seek out interdisciplinary collaborations to broaden the existing network.

Figure 6a. Co-authorship analysis showing collaboration among countries

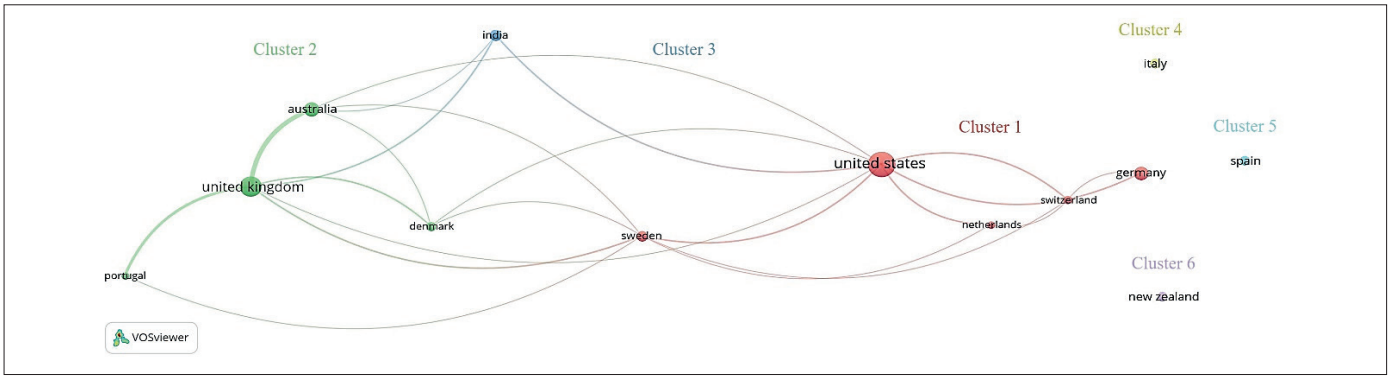
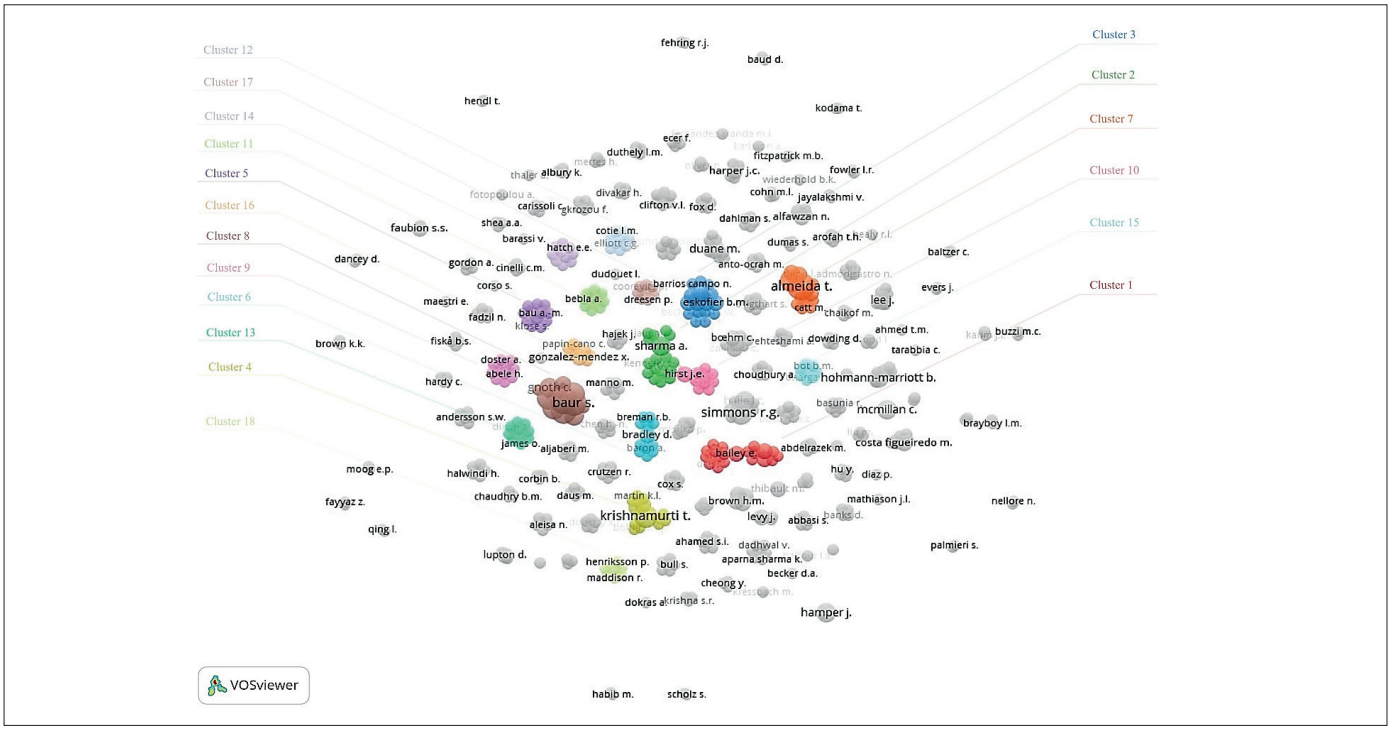


Figure 6b. Co-authorship analysis showing collaboration among authors



Bibliographic coupling

Figure 7 presents the bibliographic coupling map of documents and sources. It offered a retrospective view of how these scientific outputs were interconnected through shared references. The documents input has formed 13 clusters (see Figure 7a). Cluster 1 (red colour, at centre) included 17 items which revolved around research areas of digital future, data-driven females' health, gendered digital health apps, and women's empowerment through a variety of self-health monitoring apps (e.g. women's health apps, menstruation apps, pregnancy apps, fertility apps). Contrarily, Cluster 13 (flax colour, lower centre) only involved 3 items that examined security and privacy concerns regarding health data input. The differences in number of items underlined both the highly popular topics recurringly referenced across the scholarly community and niche perspectives or less synchronized avenues that need further research. Simultaneously, the biggest cluster of cited sources has 14 items (red colour, lower left) (see Figure 7b). The unconnected map manifested approximately 40% of the sources were scattered that implied a less cohesive network of knowledge and challenges in retrieving the relevant information. The core journals aforementioned in Table 3 may come in handy by navigating readers to impactful and high relevancy documents.

Figure 7a. Bibliographic coupling map tracking the historical connections between documents

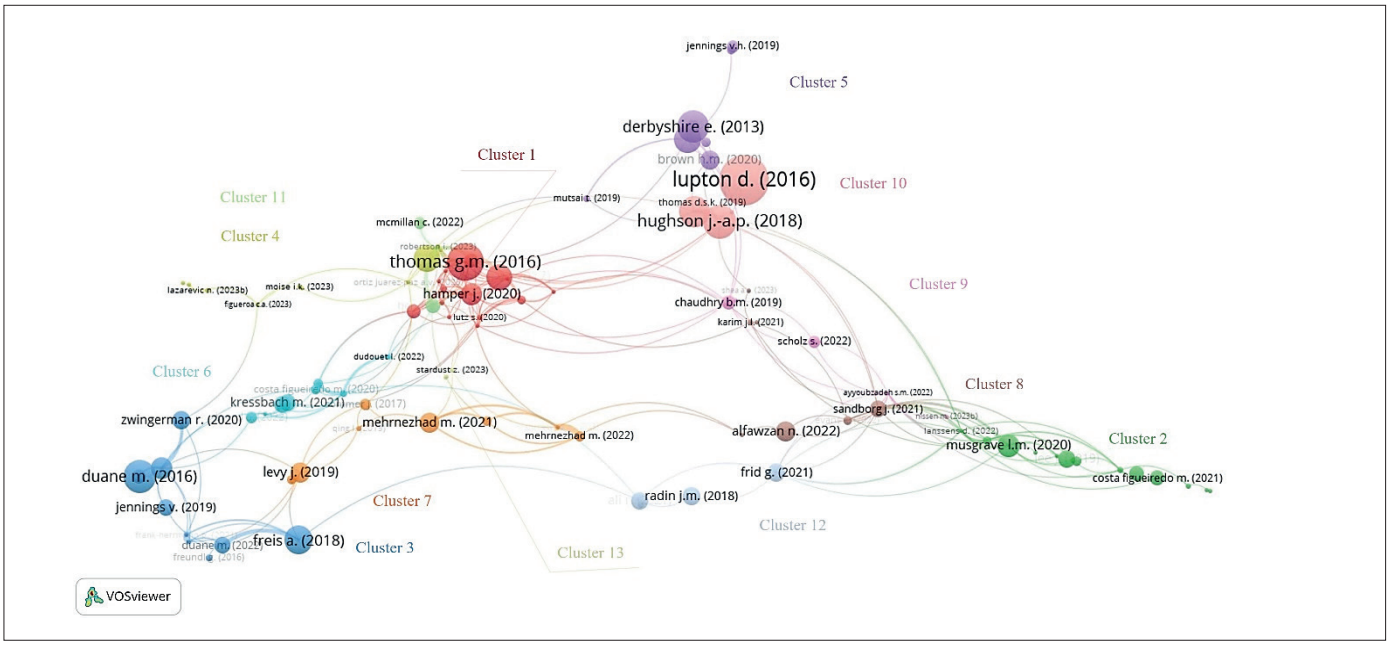
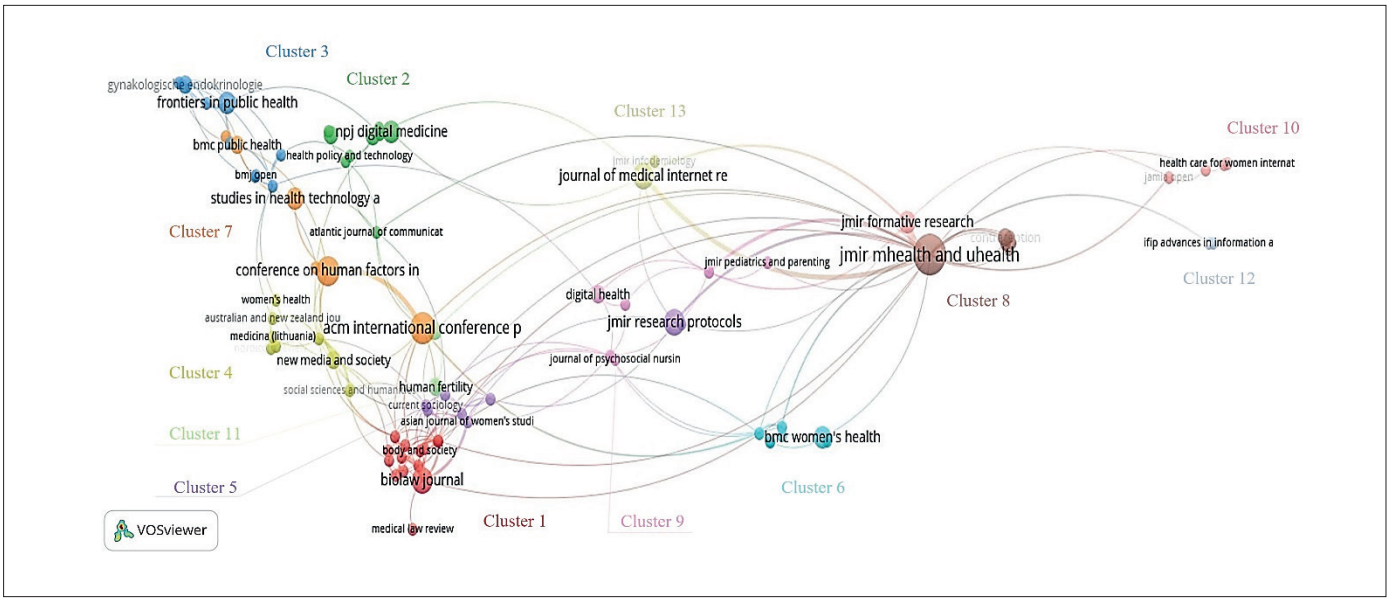


Figure 7b. Bibliographic coupling map analyzing the construction and dissemination of Femtech knowledge



Conclusion

The evolution of literary movements deciphered research contributions within Femtech domain were neither saturated nor highly competitive. The publication trends, patterns and collaborations reveal Femtech activities expand rapidly since COVID-19 pandemic era. This innovation was discussed from the perspectives of healthcare and wellness rather than technological information systems. The topics predominantly surround pregnancy, mobile apps and mHealth leading the overall research impact heavily skewed toward bikini medicine. However, the scientific communication is expanding to cover emerging topics such as telehealth, wearables, privacy, reproductive health and menopause. Most Femtech authors opted English as core language in knowledge production despite those highly prolific authors are Germans. The trends could stem from areas of affiliation, funding support and publication source that mainly came from United States and United Kingdom. Interdisciplinary collaboration of scholars merely from these countries was inadequate, peculiarly the contributions addressing Femtech ethical issues and privacy concerns. Multinational, multilingual and multicultural perspectives are vital for impactful Femtech research and boost Femtech adoption. Overall, the preceding 11 years of publications witnessed this field of research is of burgeoning interest and the growth is projected to surge substantially in the near future (Chaléat & Baud, 2023; Gkrozou et al., 2019).

Theoretical and practical implications

Present research brings significant theoretical and practical implications. The comprehensive retrospective evaluation using bibliographic approach provides holistic insights into Femtech research landscape and developments. Given the paucity of bibliometric study on Femtech, the outcomes could deepen our knowledge and understanding on Femtech research pertinent to gender health, technology adoption and allied health management. Further, the gaps and emerging themes derived from this analysis could serve as roadmap for Femtech researchers, health care providers and practitioners in setting research priorities, policy development and business practices. Femtech industry players also could explore new avenues from the Femtech research initiatives in developing Femtech solutions that meet the real-world needs. For instance, the application of new technologies such as AI, big data, robotics and ML in managing female-specific health. Proactive research, investment and support in addressing the issue related to Femtech adoption could also promote the adoption and integration of Femtech in healthcare systems. In the market, young females and adolescents born in digital age and middle and old age females who are susceptible to female health issues are potential Femtech adopters. The underrepresentation of these demographics provokes theoretical discussion and societal consequences. Uncovering these interconnections potentially led to more inclusive design principles and frameworks on information technology, highlighting how technology can empower or marginalize women.

This research also offers an opportunity to explore how technological tools, devices or systems are designed and used in ways that reflect or challenges gender norms. These themes can be drivers in achieving Sustainable Development Goals (SDG) called by the United Nation. Researchers and practitioners' initiatives or collaborations on these themes directly aligned with sustainable development goal (3-Good health and wellbeing), (5-Gender equality), (10-Reduced inequalities) and (11-Industry, innovation and infrastructure). The goal ensuring individual's good health and wellbeing not only rely on effective and efficient medicine and treatment, but also demand actions. Gender-sensitive health approaches are fundamental to combat disparities and promote good health equally. While technological progress, investment in scientific research and innovation are the key to facilitate sustainable development. In other practical way, this research enhances the visibility of Femtech research in academic and public discourse. It could raise researchers and public awareness about Femtech and gender health disparity, taboos and stigmas that stifle participation of females in economy, health and education. Awareness is the primary step to drive societal change, reinforce gender health equality initiatives and support informed policy development. In summary, the novelty of this research is it corroborated the application of bibliometric approach as a reliable and valid approach to understand Femtech research trends and provide new perspectives to extend Femtech related studies.

Limitations and future directions

Bibliometric analysis is a valuable methodology; however, the application of research outcomes should be mindful of some limitations. The research query string was set to be exhaustive by incorporating all research types related to females' health is a strength. The rich data pool provides a holistic view and broader understanding of the Femtech research activities and contributions from global perspectives. Nonetheless the data source only covers Femtech publications from the Scopus database and 11 years analysis timeline. Thus, this may challenge the data coverage and analysis results. Extending from this, the keywords and search string proposed in this research may not cover all aspects in Femtech literature as Femtech covers a broad spectrum on technology systems and females' health condition from infant to elderly and used different terminology to convey a similar concept. For illustration, "fertile window" and "fertile period" were used interchangeably. Terms such as "fertility tracking", "ovulation tracking" have gained prominence over earlier terms like "family planning" and "contraception". A literature search with different keywords could bring different results.

Considering the weakness, potential gaps could be identity to conduct bibliographic or meta-analysis on Femtech research. Future research ought to retrieve data from multiple databases. Combining Scopus database with Google Scholar or PubMed would be ideal. Google Scholar's grey literature and non-traditional publications as well as PubMed's biomedical, life sciences and healthcare research can further enrich the dataset contributing nuanced view. Simultaneously, the future research could include other keywords potentially related to Femtech. The inclusion of specific terms such as "women health innovation", "women personalized medicine", "bio-tracking", "ovulation", "mental health", "maternal" and most recent year studies may enhance the comprehensiveness and reliability of Femtech study.

Apart from going beyond these boundaries, the research and analyses captured the areas of female-oriented telehealth, telemedicine, wearable, mobile health, mobile applications, reproductive health, menopause health and ethical concerns about digital health could be a potential blue oceans. Considering the success of an innovation hinges significantly on the adoption by its intended audience. Technology adoption and human behavior theories and models such as technology acceptance model, unified theory of acceptance and use of technology, health belief model and theory of planned behavior et cetera in predicting Femtech adoption and utilization behaviors could be enhanced in order to obtain meaningful insights into the effectiveness and sustainability of Femtech solutions and its adoption among female audience.

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