ACCESS Journal:
Access to Science, Business, Innovation in Digital Economy
2026, 7(2), 331-354, https://doi.org/10.46656/access.2026.7.2(5)

ISSN 2683-1007 (Online)
https://journal.access-bg.org/

TECHNOLOGICAL ADOPTION TRENDS IN HEALTHCARE: A BIBLIOMETRIC AND NETWORK ANALYSIS ACROSS A GLOBAL TECH MANUFACTURER

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Received: December 30, 2025 *Accepted: April 13, 2026* *Online Published: April 20, 2026*

ABSTRACT

Healthcare systems worldwide face growing challenges, including aging populations, rising healthcare costs, workforce shortages, and increasing demand for equitable care. Emerging technologies are increasingly expected to address these issues and transform healthcare delivery. ***Objectives:*** *This study aims to analyze long-term trends in new technology adoption in healthcare by examining bibliometric networks of healthcare-related publications co-authored by researchers affiliated with Qualcomm, a global leader in semiconductor and telecommunications technologies.* ***Methods/Approach:*** *Using the PubMed database, healthcare-related publications co-authored by Qualcomm-affiliated researchers between 2005 and 2024 were identified and analyzed through bibliometric network analysis. VOSviewer was employed to conduct keyword co-occurrence and thematic network analyses.* ***Results:*** *Qualcomm-related healthcare research increased substantially after approximately 2014, accompanied by diversification in disease domains, diagnostic and therapeutic approaches, ethical considerations, patient-centered topics, and technological themes. Early-stage research primarily focused on health promotion and preventive care, whereas later-stage studies expanded toward diverse disease areas including HIV, diabetes, and cognitive dysfunction. Simultaneously, advanced technologies such as artificial intelligence, mobile health, telemedicine, large language models, biosignals, and wearable sensors increasingly emerged. Keywords including mobile health, research ethics, privacy, and informed consent exhibited high frequency and strong network connectivity.* ***Conclusions:*** *The findings suggest that Qualcomm's healthcare-related research evolved through four representative stages: health support, medical intervention, technological integration, and social application. These results indicate that semiconductor- and communication-based technologies may play an important role in shaping the evolution of healthcare innovation and may contribute to the development of integrated, data-driven, and digitally enabled healthcare ecosystems.*

Keywords: Digital Health; Healthcare Management; Health Innovation; Technology Adoption; Cross-sectoral Collaboration; Bibliometric Analysis

JEL classification: I15, O33, O30
Paper type: Research article

Citation: Takagi, J., Shinagawa, K., Oda, T. (2026). Technological adoption trends in healthcare: a bibliometric and network analysis across a global tech manufacturer. Access to science, business, innovation in digital economy, ACCESS Press, 7(2), 331-354, https://doi.org/10.46656/access.2026.7.2(5)

INTRODUCTION

1. Background and Motivation

Global healthcare systems are undergoing structural transformation driven by demographic and epidemiological changes. In developed economies, declining birth rates and increasing life expectancy have increased the proportion of elderly populations, thereby raising demand for continuous healthcare services,

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including long-term care (OECD, 2021). In addition, advances in precision medicine have led to more sophisticated disease classifications and increasingly complex diagnostic and treatment processes, requiring healthcare systems to adopt new technological and institutional responses (Jameson & Longo, 2015).

At the same time, rising healthcare expenditures, shortages of healthcare professionals, regional disparities in workforce distribution, and excessive workloads have become major threats to the sustainability of healthcare systems (OECD, 2019). Physician burnout, in particular, has been widely reported internationally. Shanafelt et al. (2015) demonstrated that physician burnout remains highly prevalent, while West et al. (2018) identified excessive workload, inefficient work processes, and increasing administrative burdens as contributing factors, indicating that these issues have serious consequences for both healthcare quality and workforce retention.

In contrast, in low- and middle-income countries, expanding healthcare access and ensuring equitable healthcare delivery remain critical challenges. Primary healthcare performance remains limited, and persistent problems such as shortages and maldistribution of healthcare personnel, inconsistent quality of care, and constraints in pharmaceutical and equipment supply have been reported (Bitton et al., 2019). Furthermore, the disease burden is shifting from infectious diseases toward non-communicable diseases, increasing demand for healthcare requiring continuous and advanced management (Kruk et al., 2018). Indeed, the majority of deaths caused by non-communicable diseases occur in low- and middle-income countries, where healthcare system vulnerability is considered a major contributing factor (World Health Organization, 2018).

Although healthcare challenges differ between developed and low- and middle-income countries, the application of new technologies is widely regarded as a promising means of addressing these issues. In particular, the introduction of digital and emerging technologies into healthcare has attracted increasing attention as a common solution area. Technologies such as telemedicine independent of physician or patient location, sensor-based monitoring, data-driven decision support, and integrated healthcare information management are increasingly recognized as fundamental enablers of improved efficiency, accessibility, and quality in healthcare delivery.

Moreover, these technological changes are transforming not only clinical practice but also the structure of the healthcare industry itself. The convergence of healthcare with the telecommunications, semiconductor, and information technology industries is facilitating the formation of data-driven healthcare ecosystems and the creation of new business models. This trend suggests that addressing healthcare challenges is no longer merely a matter of public health, but also one of cross-disciplinary innovation and industrial restructuring. Given that healthcare is highly regulated and demands strict ethical compliance, it represents one of the most challenging sectors for new technology adoption, making it a valuable domain for technology diffusion research.

2. Prior Research and Research Gap

2.1 Technology-Centric Studies on Healthcare Innovation

ISSN 2683-1007 (Online)
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Bibliometric and network analyses have been widely employed to investigate the adoption and evolution of emerging technologies in healthcare.

One major stream of prior research focuses on the medical applications of advanced technologies themselves. For example, AR/VR technologies associated with the metaverse have been examined in relation to surgical support, medical education, and telemedicine (Damar et al., 2024). Likewise, the integration of IoT with XR, blockchain, and robotics has been shown to enhance diagnostic support and healthcare data management (Nguyen et al., 2023). Research on robotic surgery has also visualized collaborative structures and thematic evolution through network analysis (Shen et al., 2019). From the perspective of material technologies, studies have examined co-authorship networks in quantum-dot medical applications (Krishnan et al., 2024) and temporal knowledge development in SiC-based biosensor research (Talwar et al., 2023).

These studies contribute to understanding how individual technologies are applied in healthcare; however, they primarily adopt a technology-centric perspective, emphasizing specific technologies rather than broader innovation ecosystems.

2.2 Application-Centric Studies on Digital Health and Wearables

A second stream of research focuses on wearable devices, mHealth, and digital health applications.

Misra et al. (2023) clarified structural characteristics of digital health research themes through keyword co-occurrence analysis, while Zhang et al. (2024) demonstrated the evolution of knowledge structures via cluster and time-series analyses. Kpadjouda Job et al. (2022) identified major and emerging themes through bibliometric analysis. Litvinova et al. (2023) showed that wearable devices, mHealth, IoT, and artificial intelligence constitute core research clusters. Similarly, Muñoz-Urtubia et al. (2024) and Bao et al. (2024) highlighted the emergence and temporal development of wearable-centered technologies.

These findings suggest that digital health technologies evolve as integrated clusters of multiple technological elements, rather than isolated innovations. However, prior studies remain largely application-centric, focusing on downstream healthcare implementations rather than upstream industrial enablers. In addition, recent studies have examined user behavior and perceptions related to self-tracking and fitness devices, highlighting the growing role of consumer engagement in digital health ecosystems (Dorokhova et al., 2025).

2.3 Ecosystem and Collaboration-Oriented Innovation Studies

A third research stream examines collaborative innovation networks within healthcare ecosystems.

In digital health, relationships among firms, universities, and healthcare institutions have been shown to vary across countries and contribute to innovation diffusion through knowledge sharing and technological improvement (Gu et al., 2024). In China, hospital–biomedical firm collaboration has been identified through joint patent analysis (Liu et al., 2024). Furthermore, inventor networks and intra-firm knowledge spillovers have been shown to influence research productivity (Maeki et al., 2020).

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These studies contribute to understanding healthcare innovation ecosystems from a network and collaboration perspective, but they mainly focus on meso-level institutional relationships rather than on the industrial origins of enabling technologies.

2.4 Research Gap: Lack of Industrial Actor Perspective

Although prior studies have significantly advanced understanding of healthcare technology adoption, most existing research focuses on technologies, applications, healthcare systems, or collaborative structures themselves.

Limited attention has been paid to the industrial actors supporting technological innovation.

In particular, semiconductor and telecommunications firms—core providers of digital infrastructure—have rarely been examined in a long-term and systematic manner despite their foundational role in enabling healthcare innovation. This omission is critical because semiconductors underpin the performance, miniaturization, energy efficiency, and connectivity of modern healthcare technologies.

Therefore, there remains a need for systematic and longitudinal analyses focusing on industrial actors that support technological innovation diffusion into healthcare.

3. Research Focus and Significance

Semiconductor firms play a foundational and cross-sectoral role within innovation ecosystems. These firms provide technologies supporting diverse areas such as medical devices, digital platforms, and communication systems, thereby enabling continuous monitoring, real-time data processing, and system interoperability.

Among such firms, Qualcomm occupies a particularly important position as both a semiconductor manufacturer and a global leader in communication technologies ranging from 3G to 5G. Qualcomm represents a unique enabling technology provider situated at the intersection of the semiconductor and telecommunications industries, making it an appropriate analytical subject for examining cross-industry technology diffusion into healthcare. The company has enabled mobile connectivity and data integration across industries while holding numerous standard essential patents, thereby acting as a key driver of technology diffusion.

By analyzing healthcare-related research involving researchers affiliated with such a company, it becomes possible to clarify how semiconductor- and communication-driven technological innovations have been introduced and developed in healthcare. This approach is significant because it enables a systematic understanding of technological development, disease evolution, and patterns of interdisciplinary convergence from the perspective of industrial actors.

4. Research Question

Based on the above discussion, this study establishes the following research question:

How have semiconductor- and communication-derived technologies been introduced and developed in healthcare research, a domain characterized by strict regulation, strong ethical requirements, and barriers to new technology adoption? Furthermore, what patterns of technological convergence can be identified in this process?

5. Research Objective and Contributions

The purpose of this study is to conduct a bibliometric network analysis of publications co-authored by researchers affiliated with Qualcomm between 2005 and 2024 in order to clarify the long-term trends of new technology adoption in healthcare.

Specifically, this study aims to:

1. Identify major disease domains and technological domains through keyword co-occurrence analysis;
2. Analyze the temporal evolution of research themes and innovation patterns;
3. Clarify the impact of semiconductor and communication technologies on healthcare innovation.

The academic contributions of this study can be summarized in three aspects. First, it introduces an actor-centered perspective focusing on global semiconductor and communication technology firms. Second, it provides a long-term analysis of healthcare technology adoption covering the period from 2005 to 2024. Third, it offers insights into the formation of cross-industry data ecosystems and business models in digital health.

METHODOLOGY

Analytical Methods

Database Selection:

PubMed was selected as the primary database for this study. PubMed comprises more than 38 million citations from MEDLINE, life science journals, and online books. Given its influence, comprehensive coverage of selected literature, and academic reliability, it was considered an appropriate source for the bibliometric analysis conducted in this research. Using this database, we compiled a bibliographic list of healthcare-related research articles co-authored by Qualcomm-affiliated researchers.

Search Strategy:

Relevant publications were retrieved for the period 2005–2024 using the following search query:

((qualcomm [Affiliation]) AND (medicine [All Fields])) AND (article [All Fields])

Based on this criterion, a total of 149 publications were identified.

Network Analysis:

The bibliographic dataset was analyzed using VOSviewer (version 1.6.20). Through this network-based approach, the study not only aimed to identify major research themes, but also to elucidate the interrelationships among emerging technologies and disease domains, thereby enabling a deeper understanding of how innovation diffuses across interdisciplinary boundaries within the healthcare field. The analysis was conducted across four timeframes—2005–2013, 2005–2016, 2005–2019, and 2005–2024—to capture

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medium- to long-term trends. This temporal segmentation enabled observation of how innovation phases driven by major technological transitions in the semiconductor and telecommunications industries have corresponded with and influenced trends in medical research over time.

VOSviewer Settings:

Type of analysis: Co-occurrence

Counting method: Full counting

Unit of analysis: Author keywords

The threshold for the minimum number of keyword occurrences was set to one across all periods.

Furthermore, to ensure the reproducibility of the network analysis and the transparency of the analytical process, Map Files (in text format) were exported from the network visualizations generated using VOSviewer.

These Map Files include key network metrics for each keyword, such as Links (number of co-occurrence connections), Total Link Strength (overall strength of co-occurrence relationships), and Occurrences (frequency of appearance). These metrics were used as the fundamental data for quantitatively evaluating the strength of relationships among keywords and the significance of research themes.

Key terms were extracted based on network link strength and frequency of occurrence in the co-occurrence analysis. To ensure direct interpretation of the research focus in each publication, no synonym unification was applied. This approach was adopted to preserve the original terminology used by the authors and to reflect the natural evolution of concepts and vocabulary within the respective research fields.

Scope of Analysis:

Through this approach, the study specifically examined research trends related to the introduction of new technologies into healthcare with a focus on Qualcomm. The analysis highlighted the focal diseases/conditions and specialized technological domains, as reflected in keyword co-occurrence frequencies and network link strengths.

The methodological framework of this study provides a data-driven foundation for understanding how digital and semiconductor technologies have permeated the medical field and contributed to the restructuring of cross-industry innovation networks.

RESULTS

1. Search Outcomes and Publication Trends

Figure 1 presents the cumulative number of medical-related publications co-authored by Qualcomm-affiliated researchers, as identified in PubMed between 2005 and 2024 under the specified search conditions.

The bibliometric analysis revealed a clear upward trend in the number of publications over time. Notably, a marked acceleration was observed beginning around 2014, suggesting that this period represented a turning point at which Qualcomm's research activity in the healthcare domain became significantly more prominent.

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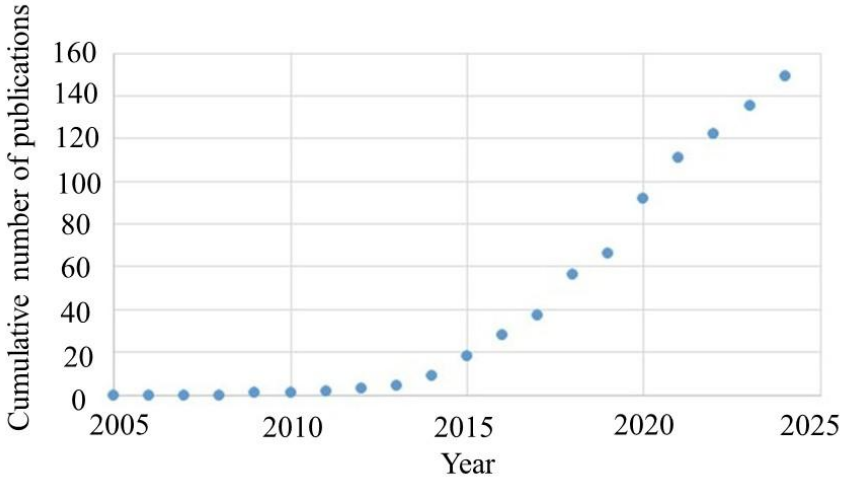

Figure 1. Cumulative number of medical-related publications co-authored by Qualcomm-affiliated researchers from 2005 to 2024

2. Analysis Results for 2005–2013

Figure 2 presents the results of the network visualization of healthcare-related publications co-authored by Qualcomm-affiliated researchers between 2005 and 2013.

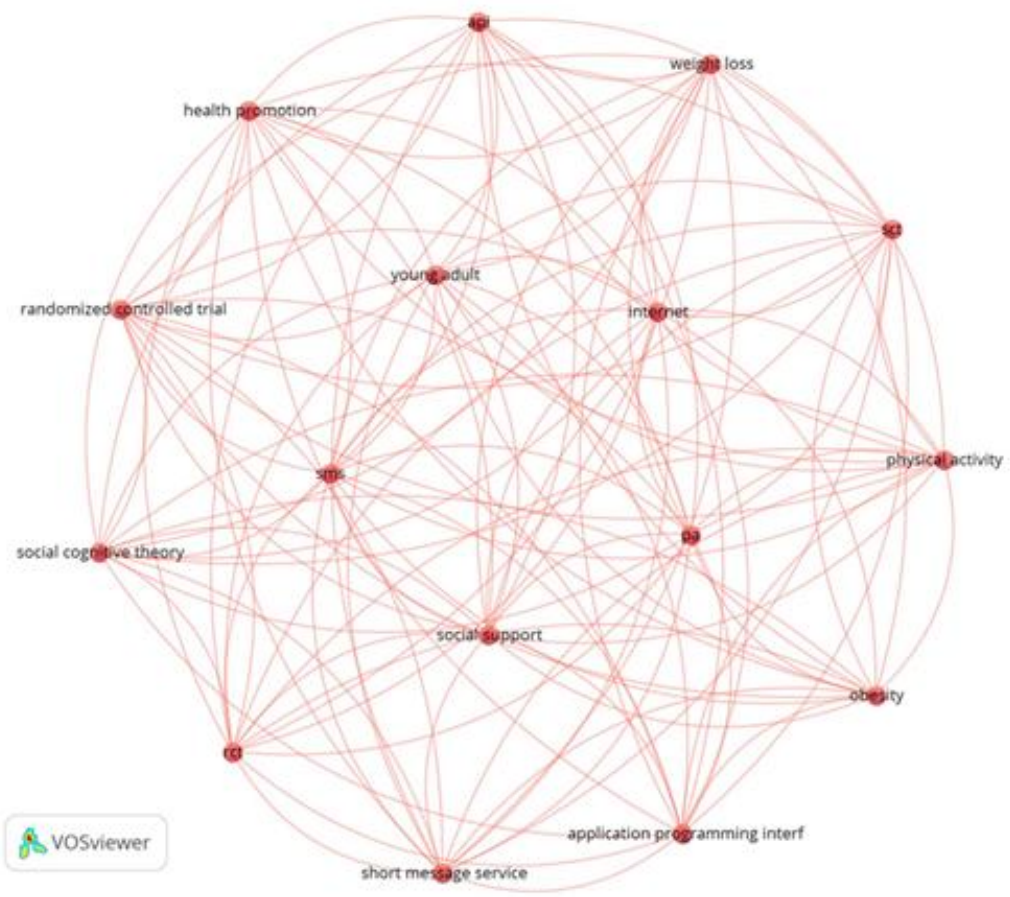

Figure 2. Network visualization based on bibliographic data of published papers in the medical field authored by Qualcomm from 2005 to 2013

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Node size represents the Occurrences of each keyword, Links indicate the number of co-occurrence connections between keywords, and link thickness reflects the Total Link Strength of the co-occurrence relationships. Based on co-occurrence analysis using VOSviewer, a total of 16 keywords were extracted from four publications, forming a single cluster.

Table 1 presents the results of Keyword Links and Occurrences of Medical-Related publications co-authored by Qualcomm-affiliated researchers between 2005 and 2013. Each keyword appeared only once, with no notable differences in Links or Occurrences. Technologies originating from the telecommunications and semiconductor industries exhibit a tendency to enter the medical-healthcare sector initially through preventive medicine and health management applications, rather than through advanced clinical domains such as diagnosis and treatment.

Table 1. Links and Occurrences of Keywords in Medical-Related Publications Co-authored by Qualcomm-Affiliated Researchers from 2005 to 2013

id	label	weight<Links>	weight<Occurrences>
1	api	15	1
2	application programming interface	15	1
3	health promotion	15	1
4	internet	15	1
5	obesity	15	1
6	pa	15	1
7	physical activity	15	1
8	randomized controlled trial	15	1
9	rct	15	1
10	sct	15	1
11	short message service	15	1
12	sms	15	1
13	social cognitive theory	15	1
14	social support	15	1
15	weight loss	15	1
16	young adult	15	1

Source: Author's co-occurrence network analysis based on PubMed data (2005–2013), conducted using VOSviewer.

In this study, the term *"Healthcare"* is used to denote activities related to the management and support of overall health, including prevention, lifestyle improvement, and rehabilitation. Accordingly, *Healthcare* encompasses broad approaches aimed at supporting health and preventing disease. In contrast, *"Health care"* refers to the professional practice of medicine, focusing on the diagnosis, treatment, surgery, medication, and management of specific illnesses and diseases. This domain includes areas where specialized medical

procedures are performed by healthcare professionals, such as prescription medication and surgical interventions.

Within the 2005–2013 dataset, *Health care*–related keywords included "randomized controlled trial (RCT)" and "sentence completion test (SCT)." By contrast, *Healthcare*-related keywords included *health promotion, obesity, physical activity,* and *weight loss.* In addition, technical keywords such as internet, API, and short message service (SMS) were identified, representing foundational information technology infrastructure.

3. Analysis Results for 2005–2016

Figure 3 presents the results of the network visualization of healthcare-related publications co-authored by Qualcomm-affiliated researchers between 2005 and 2016.

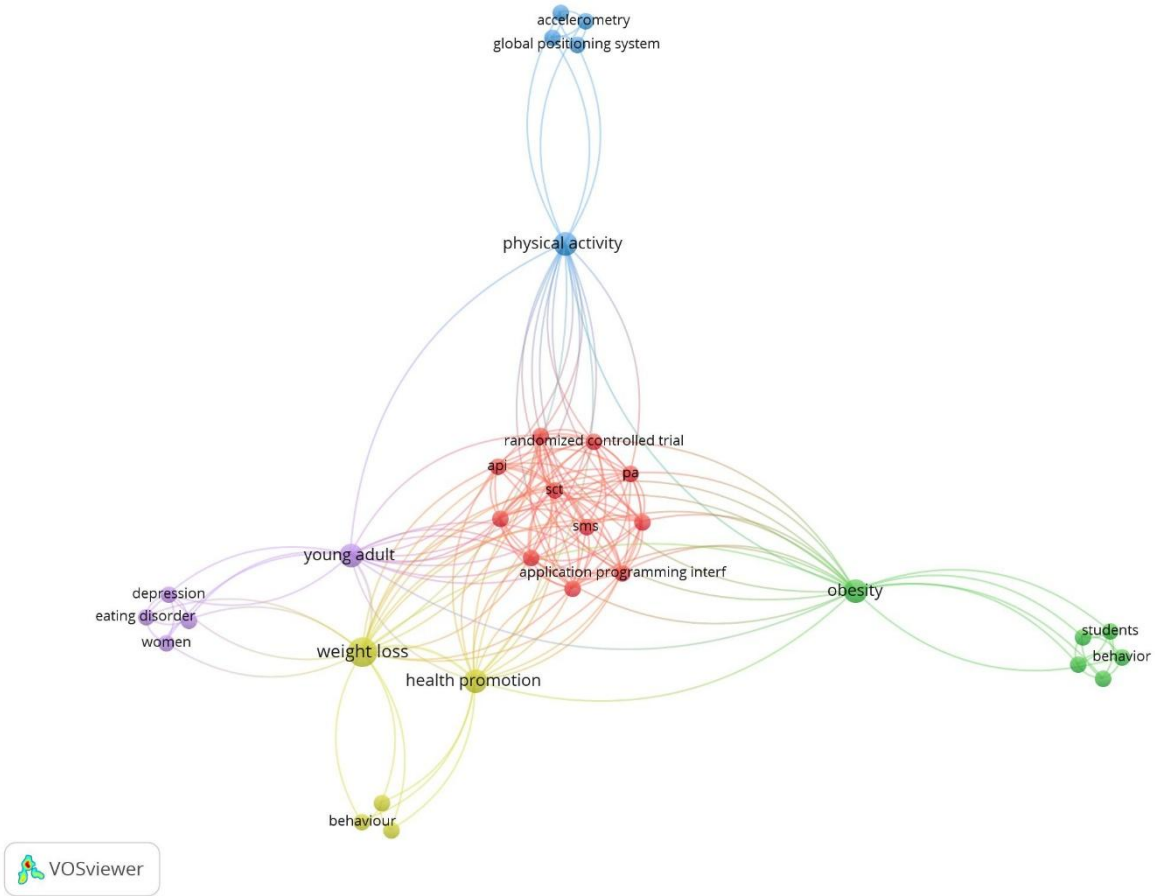

Figure 3. Network visualization based on bibliographic data of published papers in the medical field authored by Qualcomm from 2005 to 2016

Node size represents the Occurrences of each keyword, Links indicate the number of co-occurrence connections between keywords, and link thickness reflects the Total Link Strength of the co-occurrence relationships. Through co-occurrence analysis using VOSviewer, a total of 32 keywords were extracted from

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28 publications, forming five distinct clusters. The network analysis revealed that the number of keywords and the clusters increased during 2013–2016, indicating a substantial diversification of research themes.

Table 2 presents the results of Links, Total link strength and Occurrences of Major Keywords in Medical-Related Publications Co-authored by Qualcomm-Affiliated Researchers from 2005 to 2016.

With respect to keyword prominence, terms such as health promotion, obesity, physical activity, weight loss, and young adult exhibited a high number of Links, strong Total Link Strength and high Occurrences underscoring their centrality within the research network during this period. In the analyzed dataset, for the first time, disease-related keywords such as *depression* and *eating disorder* appeared in the company's research portfolio.

Table 2. Links, Total link strength and Occurrences of Major Keywords in Medical-Related Publications Co-authored by Qualcomm-Affiliated Researchers from 2005 to 2016

id	label	weight<Links>	weight<Total link strength>	weight<Occurrences>
75	weight loss	22	24	3
42	obesity	20	20	2
78	young adult	19	20	2
47	physical activity	19	19	2
28	health promotion	18	19	2
7	api	15	15	1
32	internet	15	15	1
44	pa	15	15	1
52	randomized controlled trial	15	15	1
54	rct	15	15	1
58	sct	15	15	1
61	sms	15	15	1
63	social cognitive theory	15	15	1
65	social support	15	15	1

Source: Author's co-occurrence network analysis based on PubMed data (2005–2016), conducted using VOSviewer.

Additional *Health care*–oriented terms, reflecting professional medical interventions, included "randomized controlled trial (RCT)" and "sentence completion test (SCT)," both of which had been observed in the earlier period, along with the newly emerging term "physician assistant (PA)." Meanwhile, *Healthcare*–related terms, reflecting broader approaches to health management and support, continued to include "health promotion," "obesity," "physical activity," and "weight loss," consistent with the findings up to 2013. These keywords indicate the coexistence of clinical themes and lifestyle-oriented research topics. From a technological perspective, information technology–related terms such as *API, internet, short message service*

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(SMS), and *social networking* were identified, alongside measurement and sensing technologies such as *accelerometry* and *global positioning system (GPS)*. These can be classified as communication and sensing technologies.

4. Analysis Results for 2005–2019

(A) Overview of the Network

Figure 4 presents the results of the network visualization based on bibliometric data from research papers in the medical field co-authored by researchers affiliated with *Qualcomm* between 2005 and 2019.

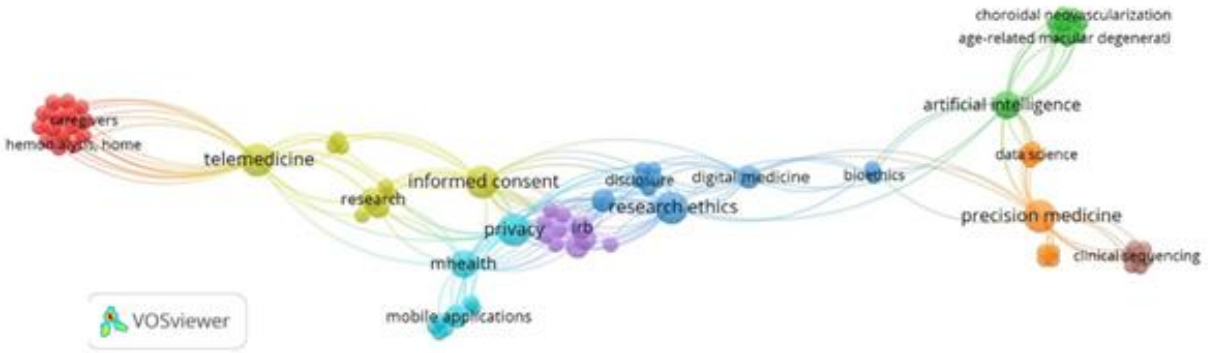

Figure 4. Network visualization based on bibliographic data of published papers in the medical field authored by Qualcomm from 2005 to 2019

Node size represents the Occurrences of each keyword, Links indicate the number of co-occurrence connections between keywords, and link thickness reflects the Total Link Strength of the co-occurrence relationships. A co-occurrence analysis using VOSviewer extracted a total of 80 keywords from 66 publications, which were organized into eight clusters. The progression from one cluster in the initial period, to five clusters in the intermediate period, and eight clusters by 2019 suggests a continuous expansion and increasing complexity of Medical-related applications, indicating a gradual maturation of technology diffusion into the healthcare sector.

Table 3. Links, Total link strength and Occurrences of Major Keywords in Medical-Related Publications Co-authored by Qualcomm-Affiliated Researchers from 2005 to 2019

id	label	weight<Links>	weight<Total link strength>	weight<Occurrences>
99	informed consent	27	32	4
140	privacy	27	31	4
177	telemedicine	26	29	4
152	research ethics	24	31	4
111	mhealth	22	22	3

136	precision medicine	20	21	4
113	mobile health	19	22	2
11	artificial intelligence	18	19	3
28	caregivers	15	15	1
38	cost-benefit analysis	15	15	1
49	diabetes mellitus	15	15	1
52	dialysis	15	15	1
85	health status	15	15	1
88	heart failure	15	15	1
90	hemodialysis, home	15	15	1
95	hypertension	15	15	1
116	monitoring	15	15	1
128	patient satisfaction	15	15	1
143	pulmonary disease, chronic obstructive	15	15	1
149	renal dialysis	15	15	1
161	self care	15	15	1
130	pervasive sensing	14	17	2

Source: Author's co-occurrence network analysis based on PubMed data (2005–2019), conducted using VOSviewer

Table 3 presents the results of Links, Total link strength and Occurrences of Major Keywords in Medical-Related Publications Co-authored by Qualcomm-Affiliated Researchers from 2005 to 2019.

In terms of network structure, informed consent, privacy, telemedicine, research ethics, mhealth, precision medicine, mobile health, and artificial intelligence demonstrated a high number of Links, indicating extensive connections with other keywords in the network. Furthermore, these keywords, along with pervasive sensing, exhibited strong Total Link Strength, suggesting robust co-occurrence relationships among these themes. In addition, these keywords, together with pervasive sensing, showed high Occurrences, highlighting their prominence within the research landscape. The sequential emergence of preventive-health themes, diversified application clusters, and institutionally embedded advanced healthcare technologies suggests a staged diffusion pathway of enabling technologies into healthcare.

(B) Main Thematic Shifts (Compared to 2016)

Compared with the period up to 2016, the following changes were observed.

(1) Expansion of Disease Domains

Keywords such as *age-related macular degeneration*, *choroidal neovascularization*, *cognitive dysfunction*, *diabetes mellitus*, *diabetic macular edema*, *diabetic retinopathy*, *heart failure*, *hypertension*, *pneumonia*,

ISSN 2683-1007 (Online)
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pulmonary disease, chronic obstructive pulmonary disease, *rare diseases*, and *undiagnosed diseases* appeared for the first time, indicating a broader research focus encompassing both common and specialized diseases.

(2) Advances in Diagnostic and Therapeutic Methods

Keywords such as *renal dialysis*, *hemodialysis*, *home*, *clinical sequencing*, *optical coherence tomography*, *genetic testing*, and *whole-genome sequencing* emerged during this period, suggesting a growing diversification of clinical methodologies for diagnosis and treatment.

(3) Emergence of Patient- and Ethics-Oriented Research

Newly identified patient-centered keywords included *health behavior*, *health status*, *self care*, *patient perceptions*, *patient rights*, and *patient satisfaction*. In addition, terms related to healthcare systems, ethics, and social factors—such as *informed consent*, *ethics committees*, institutional review board (IRB), *disclosure*, *privacy*, *disparities*, *quality of health care*, *healthcare delivery*, *government*, and *public health*—were also observed, suggesting an growing emphasis on ethical and institutional dimensions of medical research.

(4) Progress in Technological Integration

From a technological perspective, advanced IT-related terms such as *artificial intelligence*, *deep learning*, and *transfer learning* appeared for the first time, along with interdisciplinary terms integrating healthcare and information technology such as *mobile health*, *mHealth*, and *telemedicine*, indicating the company's expanding engagement in digital medicine.

5. Analysis Results for 2005–2024

(A) Overview of the Network

Figure 5 presents the results of the network visualization based on bibliometric data from research papers in the medical field co-authored by researchers affiliated with *Qualcomm* between 2005 and 2024.

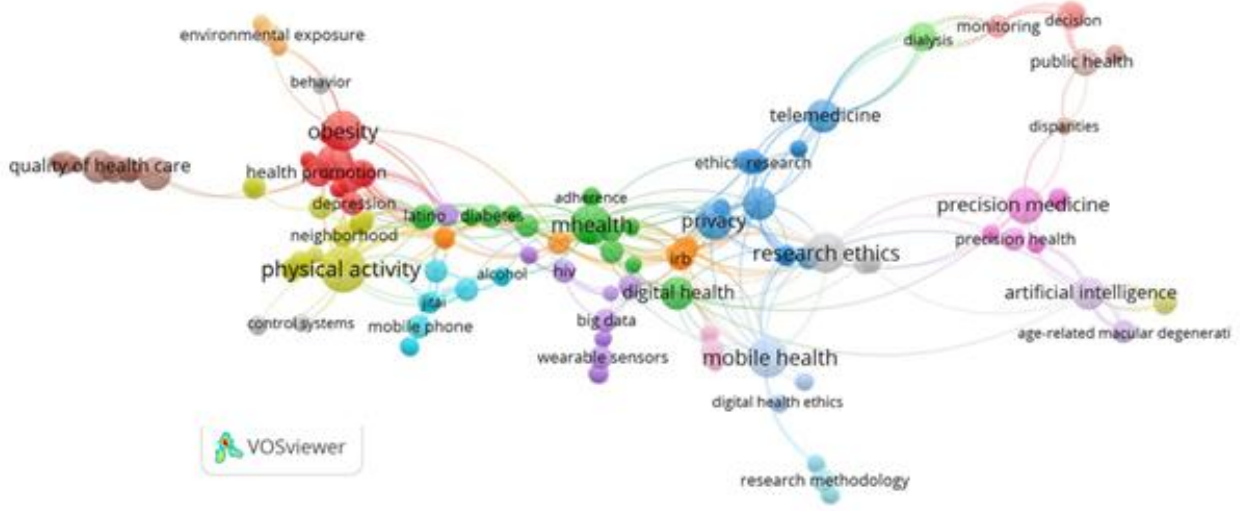

Figure 5. Network visualization based on bibliographic data of published papers in the medical field authored by Qualcomm from 2005 to 2024

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A co-occurrence analysis using VOSviewer extracted a total of 284 keywords from 149 publications, which were organized into 22 clusters. The exponential increase in cluster number from one to twenty-two suggests not merely quantitative growth but qualitative transformation in the healthcare innovation structure.

Table 4 presents the results of Links, Total link strength and Occurrences of Major Keywords in Medical-Related Publications Co-authored by Qualcomm-Affiliated Researchers from 2005 to 2024. In terms of network structure, physical activity, research ethics, mobile health, obesity, mhealth, privacy, informed consent, monitoring, artificial intelligence, telemedicine, weight loss, precision medicine, public health, gps, health promotion, young adult, internet, digital health and walking demonstrated a high number of Links, indicating extensive connections with other keywords in the network.

Table 4. Links, Total link strength and Occurrences of Major Keywords in Medical-Related Publications Co-authored by Qualcomm-Affiliated Researchers from 2005 to 2024

id	label	weight<Links>	weight<Total link strength>	weight<Occurrences>
279	physical activity	56	61	8
320	research ethics	34	43	6
236	mobile health	39	42	6
255	obesity	36	39	6
234	mhealth	34	34	6
290	privacy	30	34	5
194	informed consent	27	32	4
240	monitoring	29	29	2
25	artificial intelligence	28	29	4
375	telemedicine	26	29	4
407	weight loss	25	29	5
285	precision medicine	23	26	5
294	public health	23	23	3
157	gps	22	22	2
164	health promotion	21	22	3
414	young adult	19	20	2
198	internet	19	19	2
108	digital health	17	17	4
403	walking	17	18	2
22	api	15	15	1
57	caregivers	15	15	1
101	diabetes mellitus	15	15	1
104	dialysis	15	15	1

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167	health status	15	15	1
173	heart failure	15	15	1
175	hemodialysis, home	15	15	1
187	hypertension	15	15	1
263	pa	15	15	1
271	patient satisfaction	15	15	1
297	pulmonary disease, chronic obstructive pulmonary disease	15	15	1
307	rct	15	15	1
317	renal dialysis	15	15	1
334	sct	15	15	1
338	self care	15	15	1
350	sms	15	15	1
353	social cognitive theory	15	15	1
358	social support	15	15	1
277	pervasive sensing	14	17	2
202	irb	14	17	2
221	location tracking	14	17	2

Source: Author's co-occurrence network analysis based on PubMed data (2005–2024), conducted using VOSviewer

Furthermore, physical activity, research ethics, mobile health, obesity, mhealth, privacy, informed consent, monitoring, artificial intelligence, telemedicine, weight loss, precision medicine, public health, gps, health promotion, young adult, internet, digital health, walking, pervasive sensing, irb and location tracking exhibited strong Total Link Strength, suggesting robust co-occurrence relationships among these themes. In addition, physical activity, research ethics, mobile health, obesity, mhealth, privacy, informed consent, artificial intelligence, telemedicine, weight loss, precision medicine, public health, health promotion and digital health showed high Occurrences, highlighting their prominence within the research landscape. The coexistence of technological, clinical, and governance-related themes suggests that the healthcare diffusion of Qualcomm-related technologies has transitioned from isolated application adoption toward ecosystem-level institutional integration.

(B) Main Thematic Shifts (Compared to 2019)

Compared with the period up to 2019, the following changes were observed.

(1) Expansion of Disease Domains

Keywords such as *age-related macular degeneration*, *choroidal neovascularization*, *latent tuberculosis infection (LTBI)*, *depression*, *back pain*, *cognitive dysfunction*, *diabetes*, *diabetic macular edema*, *diabetic*

retinopathy, *heart failure*, *hypertension*, *dermatitis*, *HIV*, *eating disorder*, *pulmonary disease*, *chronic obstructive pulmonary disease*, *pneumonia*, *rare diseases*, *prematurity*, *preterm birth*, *undiagnosed diseases*, *spinal diseases*, *spinal disorders*, *suicidal ideation*, and *frailty and physical function* were newly identified, indicating an expansion of research topics related to diseases and symptoms.

(2) Advances in Diagnosis and Therapeutic Methods

Beyond the diagnostic and therapeutic keywords previously observed up to 2019—such as *renal dialysis*, *hemodialysis*, *home*, *clinical sequencing*, *optical coherence tomography*, *genetic testing*, and *whole-genome sequencing*—numerous additional keywords emerged during 2005–2024. These included *accelerometers*, *accelerometry*, *blood pressure*, *glucose*, *HbA1c*, *monitoring*, *screening*, *measurement*, *sleep*, *sitting time*, *real-world data*, *remote assessment*, *remote data collection*, and *video directly observed therapy (VDOT)*, reflecting diversification in diagnostic targets, monitoring technologies, and analytical approaches.

(3) Progress in Patient- and Ethics-Oriented Research

Patient-centered keywords—such as *behavior*, *behavioural*, *behavioral health*, *psychological well-being*, *social behavior*, *self care*, *self-help*, *patient acceptance of healthcare*, *patient engagement*, *patient perceptions*, *patient rights*, *patient satisfaction*, *social support*, *well-being*, and *mood*—were identified, showing an increased emphasis on patients' psychological and behavioral dimensions compared with 2019. Furthermore, terms related to healthcare systems, ethics, and social factors—such as *informed consent*, *ethics committees*, *IRB*, *institutional review board*, *research ethics*, *privacy*, *human subjects protection*, *personal genetic information*, *disparities*, *health disparities*, *quality of health care*, *delivery of health care*, *primary health care*, *social support*, and *public health*—were also observed, indicating an expansion of research into ethical and institutional considerations.

(4) Progress in Technological Integration

Technological terms such as *artificial intelligence (AI)*, *deep learning*, and *transfer learning* continued to appear, consistent with the previous period. However, new emerging terms—including *large language model (LLM)*, *ChatGPT*, and *text analysis*—were observed during 2005–2024. In addition, *biosignals*, *wearable sensors*, *sedentary accumulation patterns*, and *sedentary behaviour patterns* were identified, highlighting the growing application of sensing technologies and wearable devices in medical contexts.

DISCUSSION

1. Considerations for 2005–2013

During the period from 2005 to 2013, research appears to have focused on the application of information technologies such as the internet, SMS, and application programming interfaces (APIs)—interfaces that enable software functionalities and services to be accessed by other software—in relation to health promotion, obesity prevention, physical activity, and weight loss, as well as in studies employing randomized controlled trials (RCTs) and social cognitive theory (SCT). This period can be characterized as one in which Qualcomm's initiatives were primarily oriented toward "Healthcare," with a particular emphasis on the management and

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support of overall health. It can be inferred that, rather than focusing on medical practice itself, the social implementation of digital technologies supporting prevention and behavior modification had begun to advance.

It should also be noted that 2005–2013 coincided with the transition of mobile communication standards from 3G to 4G and represented a turning point in the broader consumer market, with the widespread adoption of mobile internet and smartphones. Leveraging its strength in multi-protocol technologies that enabled stable internet connectivity and SMS transmission across heterogeneous communication systems, Qualcomm is presumed to have advanced research related to the integration of internet connectivity and communication functions into medical and healthcare devices during this era. It is also presumed that the company contributed to the development of foundational digital infrastructure. Furthermore, by providing a set of application programming interfaces (APIs) that allowed direct access to communication control, SMS, and device-level operations, the company is considered to have supported and facilitated research in the medical and healthcare domains. At that time, the medical application of such communication technologies was not yet common in the healthcare field, indicating the early stage of spillover of digital and communication technologies from the information and communication industry to the medical industry.

2. Considerations for 2005–2016

Between 2014 and 2016, research activities began to shift from a preventive orientation associated with “Healthcare” toward the more medically oriented domain of “Health care” This period may be regarded as the nascent stage of Qualcomm’s research aimed at direct intervention within clinical settings.

Notably, new keywords such as social networking, accelerometry, and global positioning system (GPS) emerged during this timeframe. From 2013 to 2016, it is presumed that studies were conducted on implementing continuous connectivity and notification functions that linked social networking platforms with medical and healthcare devices. Concurrently, GPS technologies were likely employed to track participants’ locations, while accelerometry was used to quantitatively assess physical movements and postures.

It can be inferred that these research efforts were supported by Qualcomm’s strengths in multi-protocol technologies, which ensured stable internet connectivity and SMS transmission across heterogeneous communication standards, as well as its provision of application programming interfaces (APIs) that enabled direct access to communication control and device functionalities. These technological assets are considered to have facilitated and supported the company’s early-stage research in medical and healthcare applications. These initiatives may be interpreted as representing the early stage of digital convergence across the boundary between the telecommunications and healthcare industries, and are considered to have contributing to the later development of cross-sectoral innovation in later fields such as mHealth and digital health.

3. Considerations for 2005–2019

By 2005–2019, both medically specialized terms associated with “health care” and technologically advanced keywords had significantly increased compared with those up to 2016.

(1) Expansion of Disease Domains and Deepening of Medical Research

Among infectious diseases, pneumonia appeared, indicating that the company began to engage in research in the field of infectious diseases between 2017 and 2019.

For non-communicable diseases (NCDs), four new categories of keywords were identified:

・Metabolic and cardiovascular diseases: diabetes mellitus and its complications (diabetic macular edema, diabetic retinopathy) were observed, along with hypertension and heart failure. Since heart failure frequently arises from diabetes mellitus or hypertension, the emergence of dialysis and renal dialysis suggests research on therapeutic methods addressing the progression of metabolic disorders.

・Neuropsychiatric diseases: In addition to cognitive dysfunction, the keyword psychological theory−strongly associated with psychiatric research−was also confirmed.

・Ophthalmological diseases: age-related macular degeneration and choroidal neovascularization appeared, along with optical coherence tomography (OCT), an imaging diagnostic technique used in retinal disease detection.

・Developmental and congenital disorders: Keywords such as rare diseases, undiagnosed diseases, and adolescent were identified, alongside whole-genome sequencing, genetic testing, genetics, and genomics, which are used for elucidating the genetic basis of congenital diseases.

These findings indicate a significant shift in the company's research focus toward non-communicable diseases between 2017 and 2019. Whereas only depression and eating disorder had been identified between 2005 and 2016, the research scope expanded considerably during this period, suggesting a phase of clinical diversification.

(2) Technological Convergence and the Expansion of AI Applications

Technological keywords such as artificial intelligence (AI), deep learning, and transfer learning appeared, alongside interdisciplinary terms bridging medicine and information technology such as mobile health (mHealth) and telemedicine. This period may represent the initial stage of convergence between AI, medical devices, and communication technologies.

Research on AI-based remote medical care and health management via mobile devices began to emerge, marking the exploratory phase for potential implementation in clinical settings.

(3) Institutionalization of Ethics, Governance, and Research Environments

Keywords related to medical systems, ethics, and social dimensions—such as privacy, research ethics, and informed consent—appeared frequently and exhibited strong network connections. This suggests that the company approached the application of novel technologies in healthcare comprehensively, emphasizing patient protection and regulatory compliance.

During this period, the advancement of AI and telemedicine necessitated the establishment of ethical governance frameworks, reflecting an emerging awareness of balancing technological innovation with ethical responsibility.

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(4) Industrial Transition through the Convergence of Communication and AI

The years 2017–2019 marked a transitional phase characterized by the maturation of the smartphone market and the early introduction of 5G communication technology, following the dominance of 4G. During this time, the company adopted an edge-AI strategy, integrating communication, sensing, and low-power computing.

The company's technological focus appears to have centered on enabling AI to operate efficiently, intelligently, and with low power consumption within mobile devices. It is plausible that under this strategic framework, the company also advanced research applying embedded AI modules in medical and healthcare devices—for instance, facial recognition, speech and image recognition, and real-time object detection via cameras—to optimize inference and support clinical decision-making.

Given that the volume of available training data in medical domains is typically limited compared to consumer applications, transfer learning likely played an important role in these studies.

Moreover, in healthcare contexts requiring real-time transmission of vital data—such as remote monitoring, telemedicine, and robotic-assisted therapy - the company's stable, low-latency communication technologies likely provided critical infrastructure support. The company's platforms were reportedly designed to comply with HIPAA security standards and certified under ISO 13485, ensuring adherence to both U.S. and international regulatory requirements for medical device quality.

Considering the sensitive nature of patient information in healthcare, the company's hardware and software capabilities likely contributed to ensuring data security and supporting advanced medical research.

These findings suggest that the period between 2017 and 2019 represented the first stage in which the advancement of AI and telemedicine required the establishment of ethical governance frameworks. It can be characterized as a development phase where "technology-driven healthcare transformation" and "responsible implementation" evolved in parallel.

During this period, technological innovation grounded in semiconductor and communication technologies appears to have begun restructuring the medical research ecosystem by integrating clinical, digital, and ethical dimensions into a unified framework.

4. Considerations for 2005–2024

By 2005–2024, both medically specialized terms associated with "health care" and technologically advanced terms increased further compared with those observed up to 2019.

(1) Expansion of Disease Domains and Deepening of Medical Research

Keywords such as latent tuberculosis infection (LTBI), HIV, and diagnostic or interventional terms including video directly observed therapy (VDOT) and isolation appeared for the first time. The emergence of HIV—a disease that remains an unresolved global challenge—indicates that the company broadened its research scope in infectious diseases.

For non-communicable diseases, a wide variety of new categories were identified:

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· Metabolic disorders: HbA1c, insulin resistance, lipids, hemodialysis, home, lifestyle medicine, and weight loss were newly observed.

· Developmental and perinatal conditions: infancy, prematurity, and preterm birth appeared for the first time. While research prior to 2019 primarily focused on genomics, recent studies advanced toward contributions addressing perinatal and early-life health.

· Respiratory diseases: Keywords such as pulmonary disease, chronic obstructive pulmonary disease were newly identified.

· Dermatological disorders: dermatitis and atopic disease appeared.

· Aging and geriatric health: aging and frailty and physical function emerged as new terms, alongside caregivers, self-care, and sedentary behaviour, sitting time, and sedentary accumulation patterns, which are closely related to frailty prevention and the decline of physical activity among older adults.

These findings suggest that the research scope expanded from disease-specific domains toward a comprehensive, life-course approach encompassing perinatal to geriatric health, reflecting a shift from specialized medicine to integrated, population-level medical research.

(2) Digital and AI Transformation in Healthcare (Compared to 2019: Technological Convergence and AI Expansion)

Technological keywords such as telemedicine, digital health, and mobile health increased sharply, marking a period in which IT utilization in healthcare was studied extensively. In particular, new sensing-related terms such as biosignals and wearable sensors emerged, indicating the promotion of medical Internet of Things (IoT) research.

This transition may indicate a paradigm shift from technology-assisted diagnostics to AI-integrated, data-driven healthcare ecosystems. In this study, data-driven healthcare refers to healthcare systems in which clinical decision-making, disease management, and preventive interventions are guided by the continuous collection, analysis, and utilization of patient- and health-related data, as reflected in the emergence of keywords such as biosignals, wearable sensors, real-world data, and artificial intelligence.

A major thematic highlight between 2020 and 2024 was the appearance of large language model (LLM), and text analysis. These keywords suggest the early stage of research applying LLMs in healthcare and indicate an emerging transformation toward next-generation intelligent healthcare systems that bridge medical research and the digital economy.

(3) Social and Ethical Implications

Compared to 2019, keywords related to medical systems, ethics, and societal dimensions expanded further.

In the neuropsychological domain, terms such as suicidal ideation, mental health, mental health treatment, mood, psychological theory, social cognitive theory, psychological well-being, social support, and self-help appeared for the first time.

ISSN 2683-1007 (Online)
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Between 2020 and 2024, studies increasingly explored the inner dimensions of patients—such as mood, suicidal ideation, and psychological well-being—in conjunction with supporting disciplines like psychology and social cognitive theory, and with practical concepts such as social support and self-help for social reintegration.

This trend highlights significant research advancement in addressing persistent societal challenges within mental and neurological health.

The emergence of terms like mental health, self-help, and social support reflects a transition toward inclusive and well-being-oriented healthcare. These developments emphasize that technological innovation in medicine must be accompanied by ethical and psychological considerations, aligning with the principles of human-centered digital transformation.

Overall, the period from 2020 to 2024 may be characterized as the transition into the real-world data era, marked by the continuous integration of healthcare and everyday life data. It represents a phase in which an AI-centered digital health ecosystem has become established—one that integrates personalization, prevention, and ethics toward practical implementation in society.

CONCLUSION

This study conducted a longitudinal analysis of research trends in the medical field related to global semiconductor and telecommunications companies from 2005 to 2024 using bibliometric network analysis. The findings suggest that technological adoption in the medical field has progressed through four representative stages: health support, medical intervention, technological integration, and social application.

Beyond this descriptive framework, the study provides three major academic implications.

First, the findings suggest that innovation based on semiconductor and communication technologies may play an important role in shaping the direction of medical research and technological adoption in healthcare. Whereas previous studies have primarily focused on individual technologies or specific clinical domains, this study suggests that industrial actors may serve as driving forces for cross-sectoral innovation.

Second, the results indicate that the evolution of medical technologies does not follow a linear developmental trajectory, but rather progresses through a convergent process in which clinical and healthcare needs, digital technologies, and ethical considerations are mutually integrated. In particular, recent advances in advanced information technologies—including artificial intelligence (AI), the Internet of Things (IoT), and large language models (LLMs)—suggest a transition toward data-driven and highly intelligent healthcare systems supported by increasingly sophisticated semiconductor and communication infrastructures.

Third, this study suggests that medical innovation is becoming embedded within broader cross-industrial ecosystems. Collaboration among related industries—including medical devices, telecommunications, semiconductors, and information technology—is evolving beyond simple complementarity toward structurally interdependent relationships, thereby potentially forming the foundation for new data-centric value creation in the digital health domain.

These findings extend existing research by introducing an actor-centered perspective and provide exploratory empirical insights into how foundational technologies diffuse into the medical field over time. They also offer practical implications for industry, suggesting that firms positioned at the intersection of foundational technologies may play significant roles in future healthcare innovation ecosystems.

Nevertheless, this study has several limitations. The analysis is based solely on the PubMed database and focuses exclusively on publications associated with a single company. Therefore, future research should further examine the generalizability and robustness of these findings through the use of multiple databases and comparative analyses across firms and industries.

Overall, this study suggests that semiconductor and communication technologies constitute critical foundational technologies supporting contemporary medical transformation, and that these technologies may serve as key enablers in the transition toward integrated, data-driven, and socially implemented healthcare systems.

Conflict of interests: The authors declare no conflict of interest.

Author Contributions: J.T. K.S. and T.O. contributed to the conceptualization of the study; J.T. and K.S. developed the methodology; J.T. and K.S. performed the formal analysis; J.T. conducted the investigation; project administration was managed by J.T., K.S., and T.O.; data curation was handled by J.T., K.S., and T.O.; resources were provided by J.T., K.S., and T.O.; T.O. supervised the study; validation was carried out by K.S. and T.O.; the original draft was prepared by J.T., and the manuscript was reviewed and edited by J.T., K.S., and T.O. All authors have read and agreed to the published version of the manuscript.

Declaration of Generative AI and AI-assisted technologies in the writing process: During the preparation of this work the authors not used Generative AI or AI-assisted tools to create or alter images in manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement:

The data presented in this study are available on request from the corresponding author.

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