October 2022

BIG HEALTH RESEARCH AND TECHNOLOGY TRANSFER: TRENDS AND PROSPECTS

中国科学院科技战略咨询研究院
Institutes of Science and Development, Chinese Academy of Sciences

中国科学院上海营养与健康研究所生命科学信息中心
Shanghai Information Center for Life Sciences, Shanghai Institute of Nutrition and Health, Chinese Academy of Sciences

In partnership with

nature research custom media

Note on contributions

This research report is a collaborative effort between two institutes of the Chinese Academy of Sciences and the Springer Nature Research Custom Media team. The Institutes of Science and Development, Chinese Academy of Sciences (CASISD) was responsible for the planning of the report series, the design of overall report outline, drafting the report contents, and providing data search strategies. The Nature Research Custom Media team was in charge of editing, design and publication. The Shanghai Information Center for Life Sciences of the Shanghai Institute of Nutrition and Health (SINH), Chinese Academy of Sciences (CAS) was responsible for the classification of big health technology areas, providing keywords for bibliometric retrieval and patent classification, and drafting the sections on scientific publication analysis, technology transfer analysis and national competitiveness analysis based on the bibliometric data from the Dimensions database of Digital Science. The Shanghai Information Center for Life Sciences of SINH organized interviews with leading experts, and summarized expert views accordingly in support of the analysis of hotspots and the development trends of the big health research and technology transfer. Digital Science, a sister company of Springer Nature, was responsible for providing various data metrics on the global and Chinese big health sector.

Editorial committee

Abstract

'Big health' is a comprehensive concept to encapsulate the changing world, evolving social needs, and developments in the spectrum of new disease threats. Health-related industries have become a hotspot and focus for global development.

This study is based on the Dimensions database of Digital Science. From the perspective of research output, it combines bibliometric analysis and expert interviews to conduct a systematic analysis of the global big health industry between 2001 and 2021. It examines current research status, research hotspots, technology transfer potential and development trends, compares China's research competitiveness in big health in the global context, and proposes corresponding suggestions. The study reveals that:

1. Global research in the field of big health is growing rapidly, with nutritional health, mental health, chemotherapy, biotherapy, and surgical therapy receiving extensive attention. In particular, there are substantial research outputs in chemotherapy, surgical therapy and infectious disease control.

2. In general, China is very active in big health research. But compared with countries such as the United States, the United Kingdom, France and Germany, China is relatively lower down the global rankings in terms of average citations, and the research quality needs to be further improved. Specifically, China has carried out the most extensive international collaboration in chemotherapy; the field of disease treatment has the highest number of publications in China's big health research; relatively high research impact is seen in public health, and disease prevention and control, and health promotion in China's big health research.

3. A relatively higher technology transfer rate is seen in chemotherapy and prevention vaccine. To be specific, anti-tumour and anti-inflammatory drugs are hotspots for industry and the research community around the world. Chemotherapeutic and biotherapeutic drugs are the main areas of fund investment. The United States demonstrates strong capacity for technology transfer of research output in chemotherapy, biotherapy and physiotherapy, while China's prominent contribution in this regard lies in complementary and alternative therapy, biotherapy and surgical therapy.

4. The technology innovation and industrial pattern of the big health industry will undergo continuous changes amid the shift from disease treatment to disease prevention. New technologies, such as novel vaccines, precision medicine, intelligent health management devices, will further strengthen the development of disease prevention and health promotion; the development of new generation information technology makes disease diagnosis more precise, more portable and more intelligent; the deep integration of biotechnology and information technology will not only drive the paradigm shift in drug development, but also further improve public health services.

To meet the development needs in the field of big health, China should consider taking the following actions:

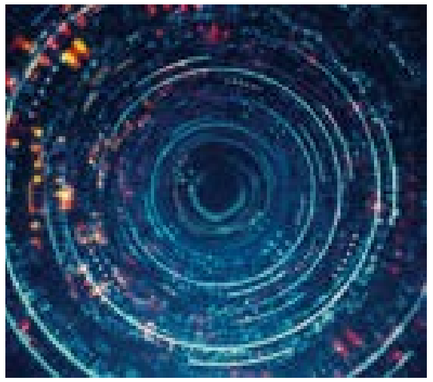
First, China should further refine the deployment of research in movement and sports , nutritional health, mental health, environmental health and in the field of preventive vaccines. China should be more forward-looking in disease prevention, promote the comprehensive integration of scientific and technological innovation with disease prevention and health promotion, and devote efforts to promoting the transfer and application of research output.

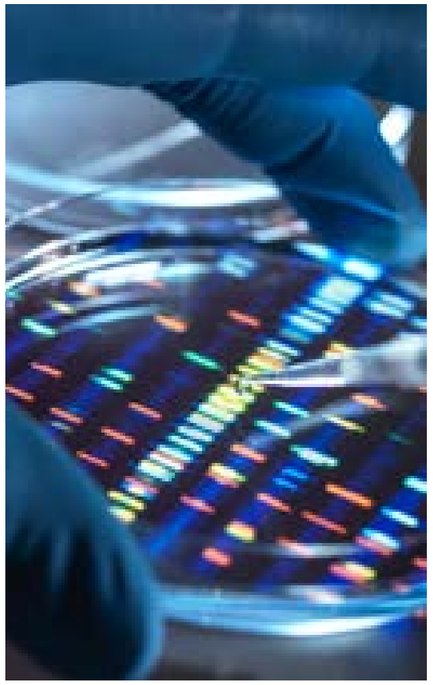
Second, China should accelerate research on medical markers that can be used for disease diagnosis, prediction, early warning and efficacy evaluation, and strengthen the development of new technologies and products for disease screening and diagnosis to achieve breakthroughs in accuracy, automation, intelligence and portability.

Third, China should strengthen research on new small molecule drugs such as PROTAC and key technologies of innovative therapies such as cell and gene therapy, promote the application of big data, artificial intelligence and other technologies in drug development, accelerate the clinical application of cutting-edge technologies for disease treatment, and improve clinical treatment.

Fourth, China should strengthen international cooperation in scientific and technological innovation in the field of public safety, actively conduct international joint research in infectious disease control, food safety, tobacco control, health education and health service, and establish a scientific and technological innovation system capable of rapid response and open for collaboration. China should continue to promote the application of digital technologies such as the big data, artificial intelligence and block chain in the public health service system, establish a digital traceability system for food and drugs and other related products, promote the development of digital medical care and mobile medical care, and accelerate intelligent development in disease prevention, clinical decision-making, health management and hospital management.

Contents





Chapter 1 Introduction

1.1 Research background and significance

The concept of 'big health' is gaining increasing public attention; health-related industries are growing with great momentum and huge potential. The COVID-19 pandemic across the globe has further raised our awareness of the importance of health, and the concepts of 'national health' and 'comprehensive health' are gaining popularity. The big health industry is also becoming increasingly important, and the demand for scientific innovation and technology transfer is skyrocketing.

Countries and regions around the world are placing importance on key technologies that will promote the development of the big health industry, and have formulated policies and initiated measures to accelerate technological innovation in a bid to get an upper hand. As the global integration of the pharmaceutical industry and other health industries is on the rise, countries continue to strengthen cooperation in regulatory measures to ensure the stable supply of drugs and medical devices to advance the development of industrial innovation. At the same time, the application of new technologies has provided prerequisites for the innovative development in life sciences, and created a large number of new health service models and new products to meet a growing need to protect health. Meanwhile, with the development of information technology, the increasing application of smart tech boosts industrial transformation and upgrading, further driven by concern about health. The combined factors have greatly contributed to the development of the big health industry.

In the face of the ever-evolving disease spectrum, ecological environment and lifestyle, China's big health industry is placing more emphasis than ever on development with the support of scientific and technological innovation. In 2016, the State Council issued the *Outline of the Healthy China 2030 Plan*, listing the big health industry as a pillar in China's economic transformation process. China has since issued a series of important documents on healthcare reform. Compared with the developed countries, China's big health industry is still in the primary stage, but the country intends to fully understand the trend, seize the opportunity, embrace the challenges and keep innovating in order to develop its big health industry. It is a national strategy to realize the coordinated development of people's health, and it is also a key move to improve China's comprehensive national strength and international competitiveness.

1.2 Definition and classification

In 2016, at the National Health Conference, President Xi Jinping stressed that 'we should advocate a healthy and positive lifestyle, establish the concept of big hygiene and big health, and shift the focus on disease treatment to people's health '. Since then, the concept of big health has become popular in China. There is no specific academic term in English for 'big health', a concept that has originated in China. The World Health Organization (WHO) defines 'health' as 'a state of complete physical, mental, moral and social well-being, not merely the absence of diseases and infirmity'. Big health is a comprehensive concept proposed according to the advancement of the times, the social needs and the evolution of the spectrum of diseases. It focuses on people's clothing, food, accommodation and transportation, as well as their life, ageing, sickness and death; it concerns various risk factors and misconceptions that affect health, and advocates health self-management. It is guided by the principle of providing all-round care during a person's entire life.

Big health not only refers to the physical health of an individual, but also includes the health in spiritual, psychological, physiological, social, environmental and moral aspects; it advocates not only a healthy life from the scientific perspective, but also reasonable healthy consumption. Big health involves all kinds of information, products and services, as well as actions taken by various organizations to meet the health needs of society. In a nutshell, big health is more extensive in scope than health and places more emphasis on the whole picture and an entire life.

On September 22, 2020, when chairing a seminar with expert participants from the field of education, culture, health, and sports, President Xi Jinping emphasized that 'we should put people's health in a strategic position of priority development, strive to guarantee people's health in all aspects in their entire life, accelerate the establishment of an institutional system, guarantee public health security, and accelerate the formation of lifestyles, modes of production, economic and social development models and governance models that are health conducive, so as to achieve the well-coordinated development of health, economy and society'. In this speech, President Xi didn't mention the term 'big health', but the essential points coincide with the holistic and the full-cycle nature of big health. In a narrow sense, big health, which is directly and highly related to health, refers to a combination of industries and sectors providing diversified products and services with the ultimate goal to maintain, improve and enhance human health.

This study is based on six aspects of medical support for health: health promotion, prevention, diagnosis, control, treatment, and rehabilitation, and combines bibliometric analysis and expert consultation to select 5 major technology areas and 20 technology themes in the big health industry (Table 1). In addition, the study conducts systematic analysis for those 5 major areas, which are disease prevention and health promotion, disease screening and diagnosis, disease treatment, disease management and public health, in a bid to reveal the development trends of technology in the big health industry in China and the developed countries, and analyse the strengths and weaknesses of China in the international comparative context, and provide reference for related research and decision-making.

1.3 Methodology and data

This study follows the research strategy of 'Data – Information – Intelligence – Solutions' (DIIS), and adopts bibliometric analysis based on the data of publications, patents, research funds and clinical trials in the Dimensions database to analyse the current research status, research hotspots, development trends, technology transfer potential, and technological concerns in the field of big health technology. Meanwhile, we invited experts and scholars in the field of big health research for in-depth interviews, and summarized the development trends of big health technology in China and around the world, the key scientific and technological issues, the development prospects and the policy evaluation. Finally, the research team made conclusions after comprehensive evaluation and analysis.

The study focuses on the current research status of technologies related to global big health industry in the past five years, including publications, patents, clinical trials and fund grants, with special emphasis on China's research output, research impact and international cooperation in the big health field. Through comparison with developed countries/regions, this study proposes technology themes that deserves special attention and development suggestions for China's big health industry.

Table 1 | 5 major technology areas and 20 technology themes in the big health industry

Technology areas	Technology themes
Disease Prevention and Health Promotion	Movement and Sports
	Nutritional Health
	Mental Health
	Environmental Health
	Prevention Vaccine
Disease Screening and Diagnosis	Diagnostic Markers
	Detection and Diagnosis Technology
	Basic research and Infrastructure
Disease Treatment	Chemotherapy
	Biotherapy
	Physiotherapy
	Surgical Treatment
	Complementary and Alternative Therapy
Disease Management	Nursing
	Medical Management Decision
Public Health	Infectious Disease Control
	Food Safety
	Tobacco Control
	Health Education
	Health Service

1.4 Report structure

This report is divided into six chapters. Chapter 1 is the introduction, while Chapter 2 provides a bibliometric analysis of big health research literature of China and the world, and reveals the trends of scientific research and the most promising technology themes in the big health field. Chapter 3 focuses on technology transfer in the big health industry, and uses data of patent citations and classifications, fund grants, and clinical trials to identify the technologies in the big health industry that attract more market attention and enjoy a higher level of technology transfer. Chapter 4 analyses and compares the research activities and research impact of developed countries in different technology themes, and explores the development patterns of the big health industry in different countries and their relative technological advantages. Chapter 5 selects the hot technology areas in the big health industry as the topics of expert interviews, and analyses the development pattern, opportunities and challenges of these technology areas. Chapter 6 provides conclusions, implications and suggestions for the future development of the big health industry.

Chapter 2

Bibliometric analysis of big health research progress

2.1 Analysis of global development trends

In this study, the global publications on various technology themes of the big health research are calculated every five years from 2002-2021 (Table 2). The findings reveal that big health research has been growing rapidly in the last 20 years, with the number of academic publications increasing from 1,201,528 in the first five-year time period (2002-2006) to 3,297,796 in the fourth five-year time period (2017-2021). Among the five technology areas, disease treatment has the highest number of publications, with 2,971,249 articles published from 2002-2021, accounting for 28.1% of the total publications in the field of big health. Disease prevention and health promotion follows closely with 2,807,256 publications from 2002-2021, accounting for 26.55% of the total publications in the field of big health.

Among the 20 technology themes, chemotherapy ranks first in terms of the number of publications with 1,775,868 articles published in the past 20 years, and the compound annual growth rate (CAGR) reaches 39.8% in the past 4 five-year periods. Infectious disease control technology comes next with 1,622,749 publications in the past 20 years, and its CAGR reaches 38.9% in the past 4 five-year periods. In addition, the publications in 17 technology themes during 2017-2021 (excluding movement and sports, complementary and alternative therapy, and nursing) account for more than 30% of the total publications in each technology theme in the last 20 years, among which the percentage exceeds 40% in six themes.

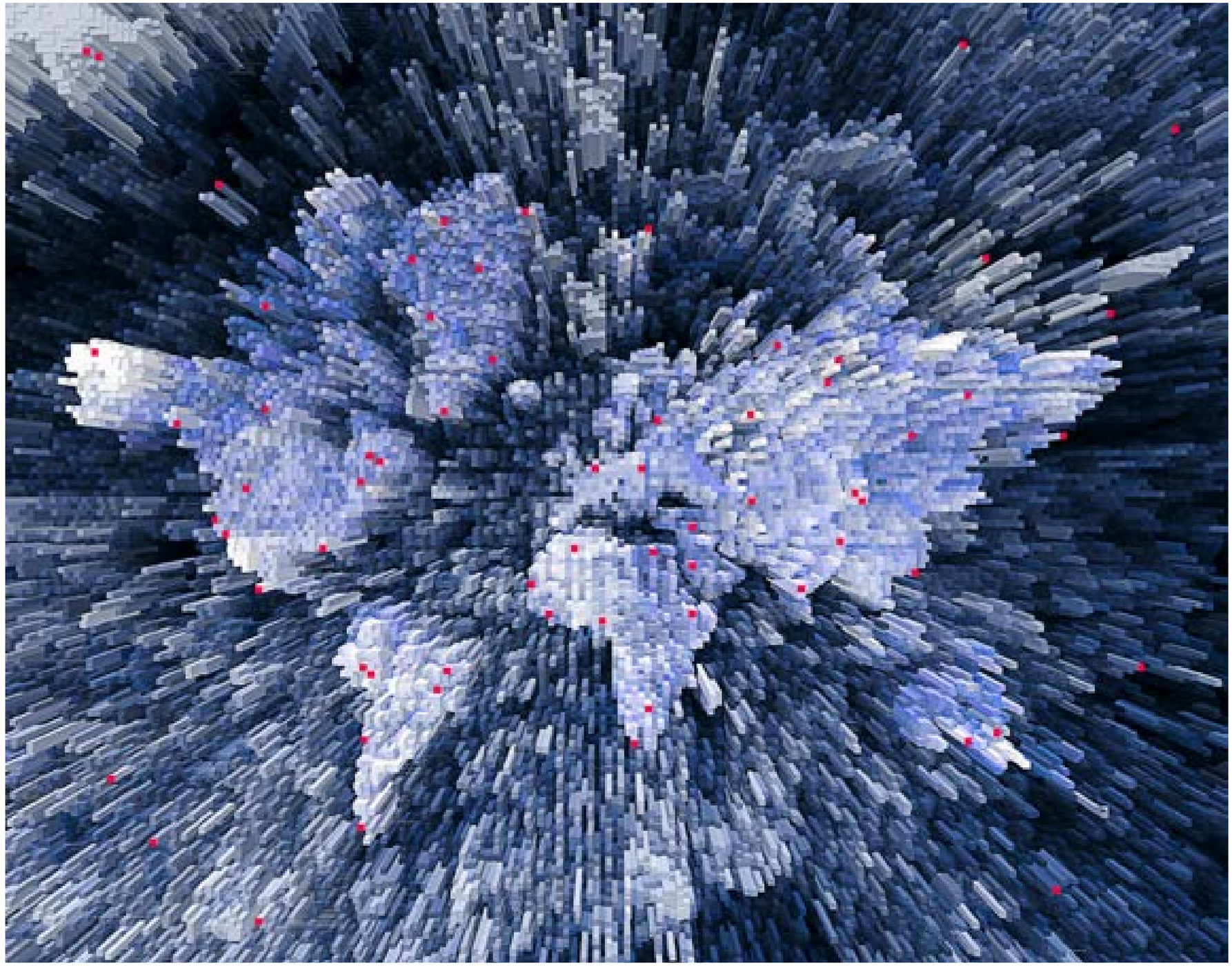


Table 2 | Number of global publications and its growth, 2002-2021

Tech. area	Tech. themes	2002-2021	2002-2006	2007-2011	2012-2016	2017-2021	2017-2021 percentage (%)	CAGR in the past 4 five-year periods (%)
Disease Prevention and Health Promotion	Movement and Sports	252,826	53,158	59,259	65,764	74,645	29.5%	12.0%
	Nutritional Health	1,056,429	125,402	200,818	299,694	430,515	40.8%	50.9%
	Mental Health	1,023,202	125,305	193,988	289,466	414,443	40.5%	49.0%
	Environmental Health	386,579	50,708	74,396	109,719	151,756	39.3%	44.1%
	Prevention Vaccine	88,220	11,094	17,384	23,591	36,151	41.0%	48.3%
Diseases Screening and Diagnosis	Diagnostic Markers	970,334	114,363	173,359	273,411	409,201	42.2%	53.0%
	Detection and Diagnosis Technology	755,517	99,172	148,604	216,688	291,053	38.5%	43.2%
	Basic research and Infrastructure	20,095	2,434	4,040	5,872	7,749	38.6%	47.1%
Disease Treatment	Chemotherapy	1,775,868	246,865	352,842	501,347	674,814	38.0%	39.8%
	Biotherapy	591,378	79,068	125,249	173,958	213,103	36.0%	39.2%
	Physiotherapy	156,021	20,231	29,125	44,400	62,265	39.9%	45.5%
	Surgical Treatment	370,393	48,330	68,248	105,143	148,672	40.1%	45.4%
	Complementary and Alternative Therapy	77,589	10,731	22,808	25,354	18,696	24.1%	20.3%
Disease Management	Nursing	456,930	103,162	114,314	124,093	115,361	25.2%	3.8%
	Medical Management Decisions	160,107	20,754	30,177	45,972	63,204	39.5%	44.9%
Public Health	Infectious Disease Control	1,622,749	234,170	321,590	438,986	628,003	38.7%	38.9%
	Food Safety	104,156	16,096	22,560	29,937	35,563	34.1%	30.2%
	Tobacco Control	114,105	18,067	24,817	32,069	39,152	34.3%	29.4%
	Health Education	55,695	10,692	12,429	14,851	17,723	31.8%	18.3%
	Health Service	535,437	64,123	95,680	146,609	229,025	42.8%	52.9%

Analysing global publications (excluding China) from 2017-2021 (Table 3), we have found that the number of publications in the field of disease treatment in the past five years reaches 998,573, accounting for 27.7% of the overall publications, while the number of publications in disease management is only 127,571, accounting for 3.5% of the total publications. In terms of the growth rate of publications, except for disease management, the volume of publications in the other four technology areas in the past five years has increased significantly since 2019 and maintained a high growth rate ever since (as of 2021). In terms of specific technology themes, chemotherapy tops the list in terms of the number of publications from 2017 to 2021, with a total number of 600,014 papers published, and 142,234 papers were published in 2021 with a 40.7% year-on-year increase, but the CAGR is only 8.9%, which shows that the rapid development of chemotherapy started from 2020. This is followed by infectious disease control, with 569,798 publications over the period of 2017-2021, and the number of publications is steadily growing, with the year 2021 witnessing the peak publications of 147,250 papers. In terms of CAGR over the period of 2017-2021, preventive vaccine has the highest CAGR value of 23.4%, and the year-on-year growth rate of publications in 2021 is as high as 73.6%. It is reasonable to assume that COVID-19 pushed preventive vaccine to the top focus of global research and product development in the past two years.

Figure 1 | Number of global publications and its growth, 2017-2021

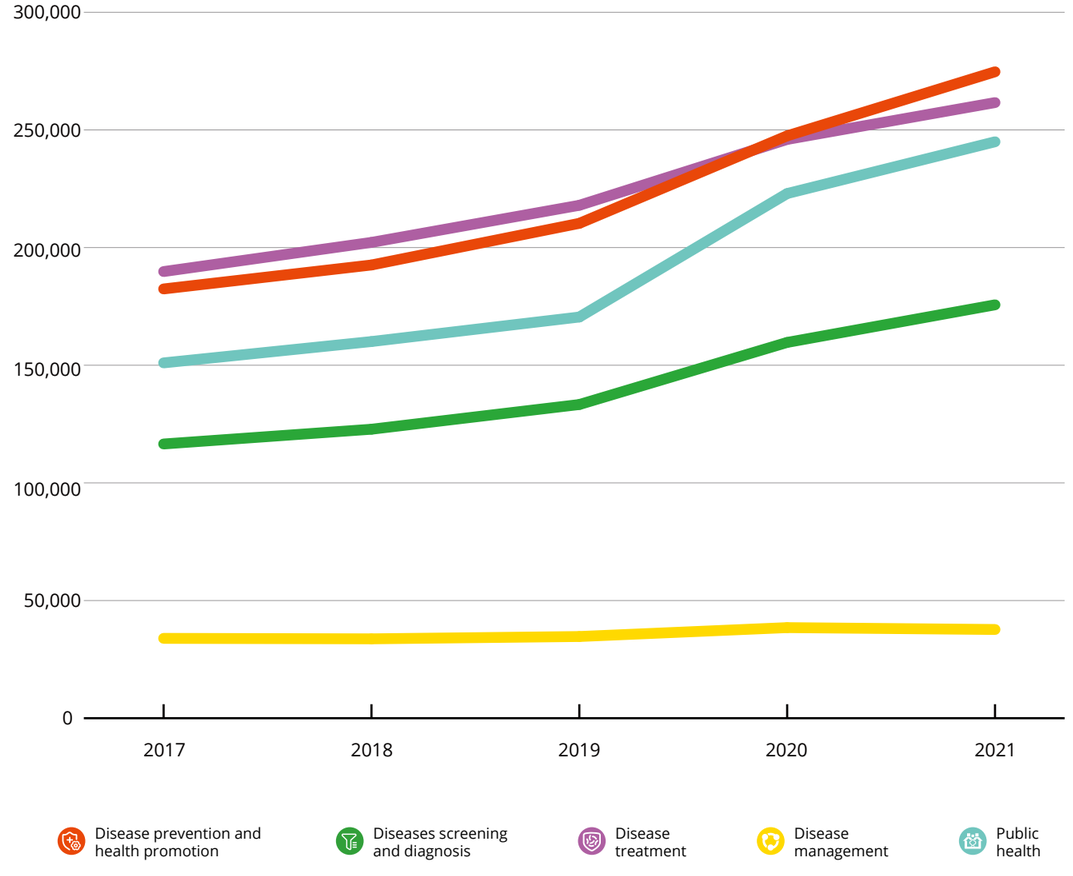


Table 3 | Number of global publications (excluding China) and its growth, 2017-2021

Tech. areas	Tech. themes	Total publications	2017	2018	2019	2020	2021	2017-2021 CAGR(%)
Disease Prevention and Health Promotion	Movement and Sports	54,053	12,678	12,223	9,661	9,883	9,608	-6.7%
	Nutritional Health	385,893	62,406	67,925	76,024	87,675	91,863	10.1%
	Mental Health	372,550	62,945	65,032	69,858	82,732	91,983	9.9%
	Environmental Health	136,817	22,775	24,266	25,869	31,182	32,725	9.5%
	Prevention Vaccine	32,566	4,752	5,001	5,436	6,351	11,026	23.4%
Diseases Screening and Diagnosis	Diagnostic Markers	365,667	59,146	62,826	68,473	83,205	92,017	11.7%
	Detection and Diagnosis Technology	271,388	46,524	48,195	51,808	60,259	64,602	8.6%
	Basic research and Infrastructure	6,169	1,075	1,192	1,238	1,350	1,314	5.1%
Disease Treatment	Chemotherapy	600,014	101,117	108,018	115,205	133,440	142,234	8.9%
	Biotherapy	198,479	34,544	36,746	39,175	42,853	45,161	6.9%
	Physiotherapy	53,281	9,320	9,889	10,337	11,556	12,179	6.9%
	Surgical Treatment	131,924	22,566	23,811	25,643	29,296	30,608	7.9%
	Complementary and Alternative Therapy	14,875	2,742	2,988	3,143	2,902	3,100	3.1%
Disease Management	Nursing	72,368	13,978	14,965	13,551	14,413	15,461	2.6%
	Medical Management Decisions	55,203	9,555	10,035	10,888	12,053	12,672	7.3%
Public Health	Infectious Disease Control	569,798	90,815	94,971	101,036	135,726	147,250	12.8%
	Food Safety	32,429	5,935	6,183	6,404	6,888	7,019	4.3%
	Tobacco Control	33,804	5,987	6,576	6,706	7,284	7,251	4.9%
	Health Education	13,408	2,277	2,412	2,539	3,131	3,049	7.6%
	Health Service	202,215	33,096	34,770	38,458	46,237	49,654	10.7%

2.2 Analysis of development trends in China

2.2.1 Analysis of research activity

China published 549,526 academic papers[1] in the field of big health over the period of 2017-2021, accounting for 16.7% of the global total in that period. Disease treatment is the most productive technology theme in big health research with 215,877 publications, which is followed by disease prevention and health promotion with 130,367 publications. Disease screening and diagnosis takes the third place with 122,632 publications (Table 4). In terms of specific technology themes, China is in line with the international trends: chemotherapy accounts for the most publications in the past five years, with 128,389 papers published, accounting for 19.0% of the global total, which is followed by infectious disease control with 90,385 publications accounting for 14.4% of the global total. In addition, China has an absolute advantage in complementary and alternative therapy, with publications during 2017-2021 accounting for 41.3% of the global total (Table 5).

In terms of growth rate (Figure 2), since 2019, the volume of publications (excluding disease management) in four major technology areas, namely disease prevention and health promotion, disease screening and diagnosis, disease treatment, and public health, has been growing at a faster rate, among which disease treatment has the highest number of publications and the fastest growth rate.

[1] The Chinese publications are calculated against the criteria that the paper should have at least one author with an affiliation in China.

Table 4 | Number of Chinese publications in five technology areas and its global shares, 2017-2021

Tech. areas	China	worldwide	Chinese global share (%)
Disease Prevention and Health Promotion	130,367	1,107,510	11.8%
Diseases Screening and Diagnosis	122,632	708,003	17.3%
Disease Treatment	215,877	1,117,550	19.3%
Disease Management	8,592	178,565	4.8%
Public Health	110,460	949,466	11.6%

Figure 2 | Number of Chinese publications, 2017-2021

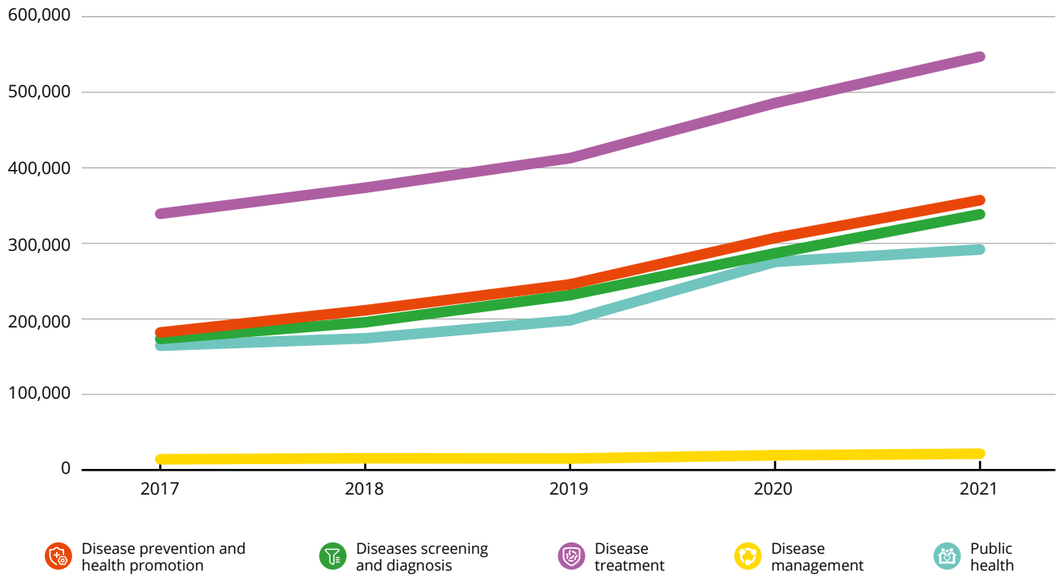


Table 5 | The Chinese publications in 20 technology themes and its global shares, 2017-2021

Tech. areas	Tech. themes	China	worldwide	Chinese global share (%)
Disease Prevention and Health Promotion	Movement and Sports	2,818	74,645	3.8%
	Nutritional Health	65,233	430,515	15.2%
	Mental Health	39,308	414,443	9.5%
	Environmental Health	19,254	151,756	12.7%
	Prevention Vaccine	3,754	36,151	10.4%
Diseases Screening and Diagnosis	Diagnostic Markers	69,147	409,201	16.9%
	Detection and Diagnosis Technology	52,917	291,053	18.2%
	Basic research and Infrastructure	568	7,749	7.3%
Disease Treatment	Chemotherapy	128,389	674,814	19.0%
	Biotherapy	50,143	213,103	23.5%
	Physiotherapy	7,867	62,265	12.6%
	Surgical Treatment	21,750	148,672	14.6%
	Complementary and Alternative Therapy	7,728	18,696	41.3%
Disease Management	Nursing	5,471	115,361	4.7%
	Medical Management Decisions	3,121	63,204	4.9%
Public Health	Infectious Disease Control	90,385	628,003	14.4%
	Food Safety	4,862	35,563	13.7%
	Tobacco Control	4,111	39,152	10.5%
	Health Education	392	17,723	2.2%
	Health Service	10,710	229,025	4.7%

2.2.2 Analysis of research impact

In terms of average citations of Chinese papers in each technology area of big health research (Table 6), public health has the best performance with an average citation of 16.1 times; disease prevention and health promotion ranks second with an average citation of 12.5 times; while disease management only has an average citation of 5.3 times.

The analysis of the relative average citation ratio (RACR)[2] of Chinese papers in each technology area of big health research reveals that the RACR values of all five technology areas are greater than one, indicating that the impact of Chinese papers is higher than the global average. To be more specific, China has the highest research impact in public health with an RACR of 1.5, which is followed by disease prevention and health promotion, and disease management, both with an RACR of 1.2.

In terms of the quality of Chinese papers in big health research (Table 7), disease prevention and health promotion performed the best with 8.4% of its publications entering the global top 10% highly cited papers[3]; public health performed the second best, with 8.3% of its publications entering the global top 10%. In terms of the number and percentage of top Chinese papers entering the top 1% most highly cited papers[4] (Table 8), health education has the best performance, with 1.3% of its publications entering the global top 1% most highly cited papers; basic research and infrastructure related to disease screening and diagnosis comes next, with 1.1% of its publications entering the global top 1%. The percentage of top 1% most highly cited papers in nursing is only 0.6%, leaving more room for improvement in the future.

[2] The relative average citation ratio (RACR) is defined as the average citations received by Chinese publications divided by the average citations received by global publications, indicating the impact of Chinese publications against the global average.

[3] Top 10% highly cited papers refer to the papers whose citations enter the global top 10%.

[4] Top 1% most highly cited papers refer to the papers of which citations enter the global top 1%.

Table 7 | Number of Chinese publications entering the global top 10%, 2017-2021

Tech. areas	Number of publications	Papers entering the global top 10%	% China in global top 10%
Disease Prevention and Health Promotion	130,367	11,004	8.4%
Diseases Screening and Diagnosis	122,632	9,559	7.8%
Disease Treatment	215,877	17,415	8.1%
Disease Management	8,592	530	6.2%
Public Health	110,460	9,119	8.3%

Table 6 | Average citations and RACR of Chinese publications, 2017-2021

Tech. areas	Number of Chinese publications	Average citations of Chinese publications	Global publications	Global average citations	RACR(%)
Disease Prevention and Health Promotion	130,367	12.5	1,107,510	10.3	1.2
Diseases Screening and Diagnosis	122,632	10.3	708,003	9.2	1.1
Disease Treatment	215,877	12.0	1,117,550	11.3	1.1
Disease Management	8,592	5.3	178,565	4.5	1.2
Public Health	110,460	16.1	949,466	10.7	1.5

Table 8 | Number of Chinese publications entering the global top 1%, 2017-2021

Tech. areas	Tech. themes	Number of publications	Papers entering the global top 1%	% China in global top 1%
Disease Prevention and Health Promotion	Movement and Sports	2,818	20	0.7%
	Nutritional Health	65,233	562	0.9%
	Mental Health	39,308	325	0.8%
	Environmental Health	19,254	172	0.9%
	Prevention Vaccine	3,754	34	0.9%
Diseases Screening and Diagnosis	Diagnostic Markers	69,147	546	0.8%
	Detection and Diagnosis Technology	52,917	408	0.8%
	Basic research and Infrastructure	568	6	1.1%
Disease Treatment	Chemotherapy	128,389	1,063	0.8%
	Biotherapy	50,143	433	0.9%
	Physiotherapy	7,867	53	0.7%
	Surgical Treatment	21,750	147	0.7%
	Complementary and Alternative Therapy	7,728	56	0.7%
Disease Management	Nursing	5,471	33	0.6%
	Medical Management Decisions	3,121	25	0.8%
Public Health	Infectious Disease Control	90,385	758	0.8%
	Food Safety	4,862	44	0.9%
	Tobacco Control	4,111	36	0.9%
	Health Education	392	5	1.3%
	Health Service	10,710	79	0.7%

2.2.3 Analysis of international cooperation

In terms of the number of Chinese publications in 20 technology themes of big health research that involves international cooperation (Table 9), chemotherapy has been most productive with 122,559 publications, accounting for a staggering 95.5% of its total publications, which is followed by infectious disease control, with 85,951 papers involving international cooperation, accounting for 95.1% of its overall publications. In terms of percentage of international cooperation papers against its total publication in individual technology themes, complementary and alternative therapy ranks first with 98.2%, which is followed by basic research and infrastructure related to disease screening and diagnosis with 97.5%.

Table 9 | Number of Chinese publications involving international cooperation, 2017-2021

Tech. areas	Tech. themes	Number of publications	Number of international cooperation papers	% of international cooperation papers
Disease Prevention and Health Promotion	Movement and Sports	2,818	2,456	87.2%
	Nutritional Health	65,233	62,369	95.6%
	Mental Health	39,308	36,774	93.6%
	Environmental Health	19,254	18,413	95.6%
	Prevention Vaccine	3,754	3,559	94.8%
Diseases Screening and Diagnosis	Diagnostic Markers	69,147	66,290	95.9%
	Detection and Diagnosis Technology	52,917	50,916	96.2%
	Basic research and Infrastructure	568	554	97.5%
Disease Treatment	Chemotherapy	128,389	122,559	95.5%
	Biotherapy	50,143	48,353	96.4%
	Physiotherapy	7,867	7,265	92.3%
	Surgical Treatment	21,750	20,588	94.7%
	Complementary and Alternative Therapy	7,728	7,591	98.2%
Disease Management	Nursing	5,471	4,966	90.8%
	Medical Management Decisions	3,121	2,819	90.3%
Public Health	Infectious Disease Control	90,385	85,951	95.1%
	Food Safety	4,862	4,685	96.4%
	Tobacco Control	4,111	3,897	94.8%
	Health Education	392	346	88.3%
	Health Service	10,710	9,469	88.4%

2.3 Identification of promising technology themes

From the bibliometric perspective, the most promising technology themes usually have a considerable volume of publications, a high growth rate, and a significant amount of papers entering the top 1% most highly cited papers. In this study, we evaluated the performance[5] of 20 technology themes in 5 technology areas of big health over the period of 2017-2021 in terms of volume of publications (Pi), compound annual growth rate (Gi), and the number of global top 1% papers in big health research (Ti) (Table 10). The top three most promising technology themes are chemotherapy, surgical treatment, infectious disease control.

[5] The formula to calculate the overall performance score:

$$Score = \frac{P_i - \min(P)}{\max(P) - \min(P)} \times \frac{1}{3} + \frac{G_i - \min(G)}{\max(G) - \min(G)} \times \frac{1}{3} + \frac{T_i - \min(T)}{\max(T) - \min(T)} \times \frac{1}{3}$$

Table 10 | The overall performance of 20 technology themes of the big health research in terms of volume, growth rate and top publications, 2017-2021

Tech. areas	Tech. themes	Total number of publications	2017	2018	2019	2020	2021	2017-2021 CAGR(%)	Top 1% publications	Overall performance score
Disease Prevention and Health Promotion	Movement and Sports	74,645	14,962	14,815	15,503	15,779	13,586	-2.4%	376	0.1
	Nutritional Health	430,515	68,753	74,766	83,546	97,943	105,507	11.3%	473	0.4
	Mental Health	414,443	68,580	70,745	76,759	92,110	106,249	11.6%	948	0.4
	Environmental Health	151,756	24,948	26,802	28,521	34,599	36,886	10.3%	3028	0.4
	Prevention Vaccine	36,151	5,179	5,470	5,967	7,061	12,474	24.6%	325	0.4
Diseases Screening and Diagnosis	Diagnostic Markers	409,201	65,844	69,940	76,420	93,201	103,796	12.1%	388	0.4
	Detection and Diagnosis Technology	291,053	49,358	51,271	55,337	64,844	70,243	9.2%	266	0.3
	Basic research and Infrastructure	7,749	1,332	1,594	1,544	1,646	1,633	5.2%	24	0.1
Disease Treatment	Chemotherapy	674,814	113,765	121,256	130,493	149,500	159,800	8.9%	2079	0.6
	Biotherapy	213,103	37,104	39,250	42,257	45,828	48,664	7.0%	1825	0.3
	Physiotherapy	62,265	10,588	11,380	12,221	13,619	14,457	8.1%	1583	0.3
	Surgical Treatment	148,672	25,015	26,644	28,921	33,256	34,836	8.6%	3668	0.5
	Complementary and Alternative Therapy	18,696	3,337	3,670	4,074	3,757	3,858	3.7%	117	0.1
Disease Management	Nursing	115,361	22,972	22,321	22,304	24,715	23,049	0.1%	247	0.1
	Medical Management Decisions	63,204	10,954	11,408	12,409	13,780	14,653	7.5%	591	0.2
Public Health	Infectious Disease Control	628,003	98,125	102,706	109,691	150,426	167,055	14.2%	285	0.5
	Food Safety	35,563	6,412	6,694	6,957	7,545	7,955	5.5%	94	0.1
	Tobacco Control	39,152	6,589	8,303	7,498	8,252	8,510	6.6%	1530	0.2
	Health Education	17,723	3,017	3,339	3,432	4,068	3,867	6.4%	4715	0.4
	Health Service	229,025	36,855	39,023	42,904	52,671	57,572	11.8%	278	0.3

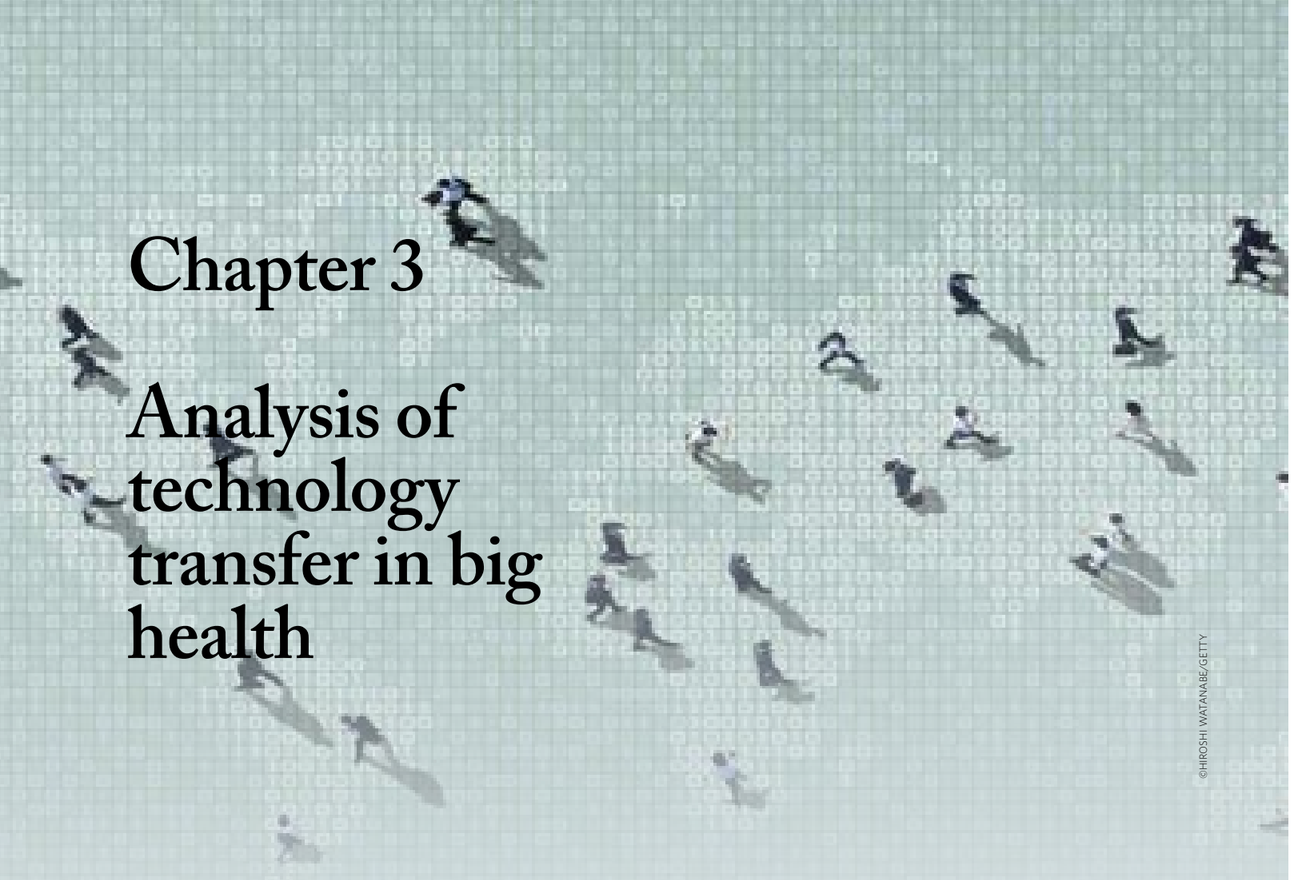
2.4 Summary

This chapter adopts bibliometric analysis of the global and Chinese publications in the field of big health to reveal the trends of scientific research.

(1) As for the global trends, big health research has experienced accelerated growth in the past 20 years, with the total number of publications reaching 8,629,075. For the 5 technology areas, disease treatment has the highest number of publications, accounting for 28.1%, followed by disease prevention and health promotion, which accounts for 26.55%. Chemotherapy and infectious disease control technology are the top 2 technology themes in terms of the number of publications, indicating that these two topics received more attention from the research community.

(2) As for big health research trends in China, Chinese authors published 549,526 papers over the period of 2017-2021, accounting for 16.7% of the global total publications in the same period. Disease treatment, disease prevention and health promotion, and disease screening and diagnosis are the top three technology areas in terms of the number of publications, which is in line with the international trend. Chemotherapy, and infectious disease prevention and control are the top two technology themes in terms of the number of publications in the past five years. The research impact analysis reveals that public health, and disease prevention and health promotion are the top 2 technology areas in terms of the average citations per paper. In China, the higher research impact is seen in three technology areas, which are public health, disease prevention and health promotion, and disease management, with the RACR of 1.5, 1.2 and 1.2, respectively. We have also revealed that China has produced the highest number of international cooperation papers in chemotherapy, accounting for a staggering 95.5% of the total publications in this field, which is followed by infectious disease control, accounting for 95.1% of the total publications in this field.

(3) A comprehensive assessment of the performance of 20 technology themes in five technology areas of big health research over the period of 2017-2021 in terms of the number of publications, the compound annual growth rate (CAGR), and the number of top 1% most highly cited papers in big health research revealed that chemotherapy, surgical treatment, infectious disease control, nutritional health, mental health, environmental health, prevention vaccine, diagnostic markers, and health education are the most promising technology themes.



Chapter 3

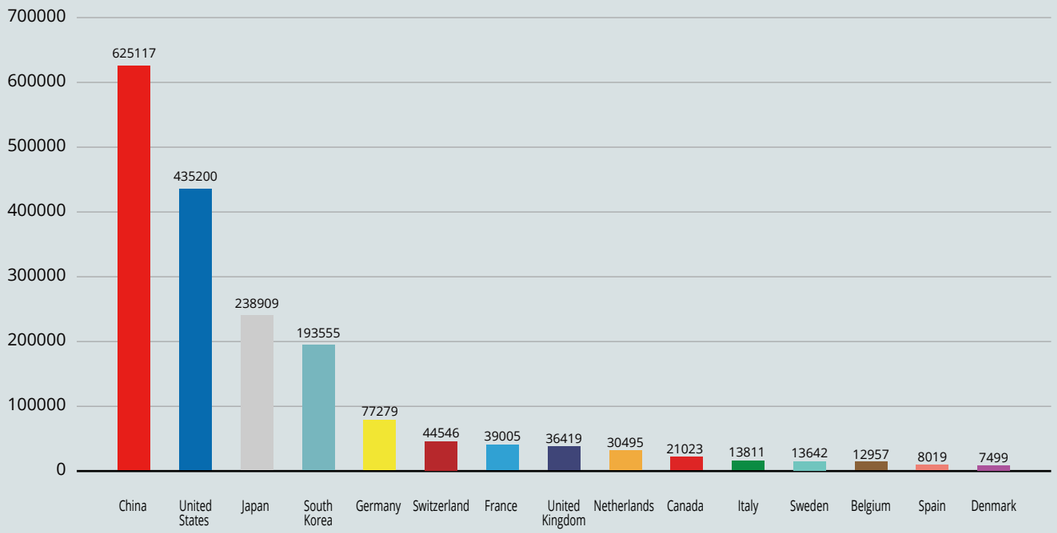
Analysis of technology transfer in big health

©HIROSHI WATANABE/GETTY

3.1 Analysis of patent citations

According to the data from Dimensions, the top 15 countries in terms of the number of patent applications in the field of big health are illustrated in Figure 3. Specifically, China and United States take the top two places with significantly higher number of patent applications than other countries, followed by Japan, South Korea, Germany and Switzerland.

Figure 3 | Number of global patent applications in big health industry by countries



In terms of the number of patents cited by papers and the number of papers cited by patents in different technology areas of big health research (Figure 4), chemotherapy, infectious disease control and biotherapy rank the global top three respectively, indicating that the these areas attracted more industrial attention. In terms of the proportion of academic papers cited by patents against the total number of academic papers in the big health field (Table 11), chemotherapy, prevention vaccine and biotherapy outperform others, indicating that a relatively large portion of research output in these technology themes have been transferred to the industry.

Figure 4 | Number of patents cited by academic papers and number of academic papers cited by patents in individual technology themes, 2017-2021

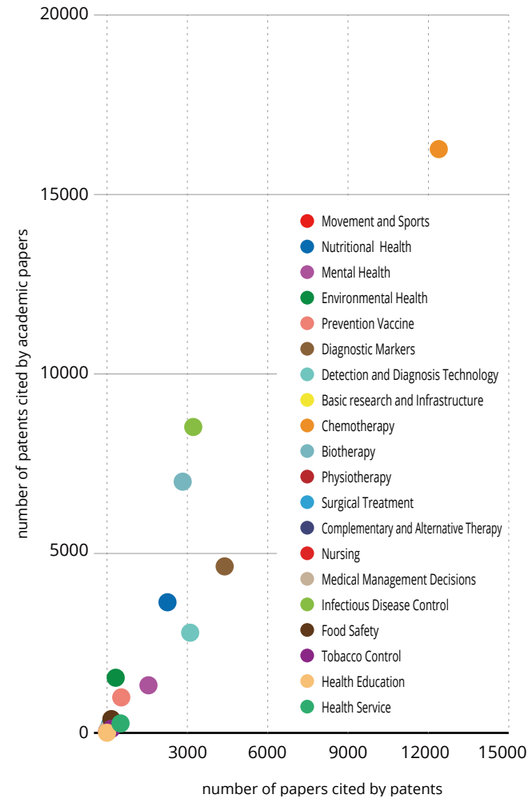


Table 11 | Proportion of papers cited by patents against the total number of papers in big health field, 2017-2021

Tech. areas	Tech. themes	percentage
Disease Prevention and Health Promotion	Movement and Sports	0.18%
	Nutritional Health	0.52%
	Mental Health	0.37%
	Environmental Health	0.21%
	Prevention Vaccine	1.47%
Diseases Screening and Diagnosis	Diagnostic Markers	1.07%
	Detection and Diagnosis Technology	1.07%
	Basic research and Infrastructure	0.79%
Disease Treatment	Chemotherapy	1.84%
	Biotherapy	1.33%
	Physiotherapy	0.25%
	Surgical Treatment	0.07%
	Complementary and Alternative Therapy	0.16%
Disease Management	Nursing	0
	Medical Management Decisions	0.04%
Public Health	Infectious Disease Control	0.51%
	Food Safety	0.46%
	Tobacco Control	0.43%
	Health Education	0
	Health Service	0.22%

In terms of the number of patents cited by Chinese papers, chemotherapy, infectious disease control and biotherapy ranks the top three, while in terms of the number of papers cited by patents, chemotherapy, diagnostic markers and infectious disease control rank the top five (Figure 5), indicating to some degree that China pays more attention to the emerging frontier technologies of the big health industry. In terms of the proportion of Chinese papers cited by patents (Table 12), prevention vaccine, basic research and infrastructure of disease screening and diagnosis, and chemotherapy outnumber others, and this can be explained mainly by external factors such as the continuous increase of tumour incidence, rapid development of diagnostic testing technology, and the outbreak of COVID-19 pandemic in recent years, as well as the increased support for these technologies in China in past years. This indicates a more abiding bond between the research community and industry in these fields. However, in the global context, the tie between Chinese papers and patents is relatively weak. By comparing the patent technology planning in China and global markets, we see similar focus on chemotherapy, infectious disease control and biotherapy, and relatively higher technology transfer rates are seen in chemotherapy and prevention vaccine.

Figure 5 | Number of Chinese patents cited by papers and number of Chinese papers cited by patents in 20 technology themes, 2017-2021

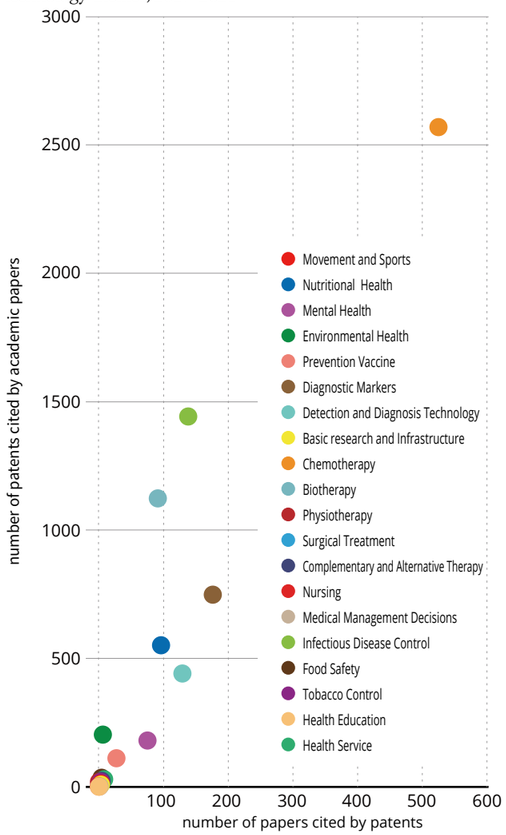


Table 12 | Proportion of Chinese papers cited by patents against the total number of Chinese papers in the big health field, 2017-2021

Tech. areas	Tech. themes	percentage
Disease Prevention and Health Promotion	Movement and Sports	0.11%
	Nutritional Health	0.15%
	Mental Health	0.19%
	Environmental Health	0.03%
	Prevention Vaccine	0.72%
Diseases Screening and Diagnosis	Diagnostic Markers	0.25%
	Detection and Diagnosis Technology	0.24%
	Basic research and Infrastructure	0.53%
Disease Treatment	Chemotherapy	0.41%
	Biotherapy	0.18%
	Physiotherapy	0
	Surgical Treatment	0
	Complementary and Alternative Therapy	0.05%
Disease Management	Nursing	0
	Medical Management Decisions	0.03%
Public Health	Infectious Disease Control	0.15%
	Food Safety	0.08%
	Tobacco Control	0.07%
	Health Education	0
	Health Service	0.07%

The country analysis of researchers whose patents are cited by papers reveals the top three countries and the number of patents cited, as shown in Table 13. In terms of the number of patents cited by papers, the United States ranks high in the major technology areas of the big health field, indicating that it attaches more importance to technology transfer of research output. In particular, in terms of the number of patents cited by papers, the United States accounts for more than 60% of the total number of top three countries in the 5 identified technology areas, namely disease prevention and health promotion, disease screening and diagnosis, disease treatment, disease management, and public health. In addition, in terms of the number of patent applications cited by papers in the global big health field, Germany, South Korea, and Japan also have outstanding performance. Considering the number of patents and its percentage, Germany is committed to promoting technology transfer in disease screening and diagnosis, and public health, while Japan pays more attention to technology transfer in disease prevention and health promotion, and disease treatment. South Korea attaches more importance to disease prevention and health promotion, disease treatment, and public health.

Table 13 | Top three countries of patentees in 5 technology areas of the big health field

Tech. areas	Countries of patentee	Number of patents cited
Disease Prevention and Health Promotion	United States	2,972
	South Korea	758
	Japan	460
Diseases Screening and Diagnosis	United States	4,440
	Germany	1,216
	South Korea	990
Disease Treatment	United States	11,159
	South Korea	1,868
	Japan	1,187
Disease Management	United States	17
	South Korea	6
	Israel	4
Public Health	United States	3,196
	South Korea	437
	Germany	222

©MALORNV/GETTY

3.2 Technology hotspots for industry and the research community

The Cooperative Patent Classification (CPC) is a patent classification system jointly developed by the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO). It contains the technical information of the patents which can be used to understand the main technology areas and technical focus of a patent. Based on the CPC classification, this report analyses the technical directions of patents cited by papers on 20 technology themes in the big health field for China and across the globe. The top five technical directions are listed in Table 14 and 15. In terms of the number of patents cited by global papers, the top five technical directions revolve around antineoplastics, special drugs, and anti-inflammatory agent and neurological therapeutic drugs, while for China, the technology hotspots are mainly in antineoplastics, and anti-inflammatory agent and neurological therapeutic drugs. In general, antineoplastics, anti-inflammatory drugs, and neurological therapeutic drugs are the hotspots of technology transfer in China and around the world.

Among the 20 technology themes in the big health field, in terms of the number of patents cited by papers, the top five technology themes are chemotherapy, biotherapy, and detection and diagnosis technologies. Based on the CPC classification, in terms of the number of patents cited by papers, this study further analyses the technical directions of the three technology themes, namely chemotherapy, biotherapy and diagnostic markers, and the top five technical directions are shown in Table 16, Table 17 and Table 18.

Table 14 | Top five technology hotspots based on the number of patents cited by global publications (data from CPC)

Patent classification number	Technology	Number of patents cited by publications
A61P35/00	Antineoplastic agents	8,251
A61K45/06	mixtures of active ingredients without chemical characteristics, e.g. anti-inflammatory agent and carditis drugs	6,387
A61P43/00	Drugs used for special purposes	5,184
A61P25/00	Drugs for the treatment of neurological disorders	3,162
A61P29/00	Non-central analgesics, antipyretics or anti-inflammatory agents, e.g. antirheumatics; non-steroidal anti-inflammatory drugs	2,896

Table 15 | Top five technology hotspots based on the number of patents cited by Chinese publications (data from CPC)

Patent classification number	Technology	Number of patents cited by publications
A61P35/00	Antineoplastic agents	424
A61K45/06	mixtures of active ingredients without chemical characteristics, e.g. anti-inflammatory agent and carditis drugs	251
A61P29/00	Non-central analgesics, antipyretics or anti-inflammatory agents, e.g. antirheumatics; non-steroidal anti-inflammatory drugs	120
A61K2300/00	Mixtures or combinations of active ingredients	119
A61P25/28	For the treatment of neurodegenerative diseases of the central nervous system, e.g. nootropic drugs, cognitive enhancers, drugs for the treatment of Alzheimer's disease or other forms of dementia	114

Table 16 | Top five technology hotspots based on the number of patents cited by papers in chemotherapy (data from CPC)

Patent classification number	Technology	Number of patents cited by publications
A61P35/00	Antineoplastic agents	6,696
A61K45/06	mixtures of active ingredients without chemical characteristics, e.g. anti-inflammatory agent and carditis drugs	4,556
A61P43/00	Drugs used for special purposes	3,824
A61P29/00	on-central analgesics, antipyretics or anti-inflammatory agents, e.g. antirheumatics; non-steroidal anti-inflammatory drugs	2,635
A61P25/00	Drugs for the treatment of neurological disorders	2,321

For chemotherapy, the top five technology hotspots are mainly related to anti-tumour drugs, anti-inflammatory agents, special drugs, and neurological therapeutic drugs. Currently, chemotherapeutics is still a popular area for antineoplastic drug development (A61P35/00); in particular, small molecule targeted drugs are in a rapid development stage, and more and more researchers are exploring chemotherapeutics by relying on novel technology platforms such as antisense oligonucleotides, small interfering RNA, and Proteolysis Targeting Chimeras (PROTAC). In addition, a couple of directions are important hotspots for technology transfer in chemotherapy research, such as mixtures of active ingredients without chemical characteristics (A61K45/06), chemotherapeutics for special purpose (A61P43/00), non-central analgesics (A61P29/00), and neurological drugs (A61P25/00).

For biotherapy technologies, the patents cited by papers focus on the following technology hotspots, such as anti-tumour drugs, stem cells and cell engineering technologies. To be specific, 'bone marrow, hematopoietic stem cells; mesenchymal stem cells of any origin, e.g. adipose-derived stem cells (ADSCs)' (A61K35/28) are the source cells of various types of stem cells; while 'lymphocytes, B cells, T cells, natural killer cells, interferon-activated or cytokine-activated lymphocytes' (A61K35/17) and 'T cell receptor (TCR)-CD3 complex' (C07K14/7051) are important individual-tailored cellular materials or editing technologies for immune cell therapy. As the most promising biotechnology in anti-tumour research in recent years, immune cell therapy has been developed and applied in various tumour treatments, such as hematological malignancies, which mainly involves corresponding gene editing and genetic modification technologies.

For diagnostic markers, the top five technology hotspots are mainly related to medical imaging and computer-aided diagnostic systems, indicating that machine learning assisted medical imaging diagnosis is the current trend for technology transfer. As we can see from Table 18, 'for computer-aided diagnosis, such as medical expert system' (G16H50/20) shows that the combination of detection and diagnosis technology with machine learning or artificial intelligence technology is the main direction of technology development; 'cancer diagnosis' (C12Q1/6886) indicates that the application of medical imaging systems in cancer diagnosis is currently the trend for technology transfer in detection and diagnosis technologies research. In addition, 'expression markers' (C12Q2600/158) and 'biomedical imaging examination' (G06T7/0012) show that the discovery of new molecular imaging targets related to cancer is a trend for new detection and diagnostic technologies. In a nutshell, we can see a recent development of sophisticated imaging equipment and deep integration of machine learning technology with diagnostic technology in recent years.

Table 17 | Top five technology hotspots based on the number of patents cited by papers in biotherapy (data from CPC)

Patent classification number	Technology	Number of patents cited by publications
A61P35/00	Antineoplastic agents	808
A61K35/28	bone marrow, hematopoietic stem cells; mesenchymal stem cells of any origin, e.g. adipose-derived stem cells (ADSCs)	517
A61K35/17	lymphocytes, B cells, T cells, natural killer cells, interferon-activated or cytokine-activated lymphocytes	426
C12N2510/00	Cells with genetic modifications	413
C07K14/7051	T cell receptor (TCR)-CD3 complex	391

Table 18 | Top five technology hotspots based on the number of patents cited by academic papers in diagnostic marker (data from CPC)

Patent classification number	Technology	Number of patents cited by publications
G16H50/20	for computer-aided diagnosis, such as medical expert system	607
C12Q2600/158	expression markers	598
G06T7/0012	biomedical imaging examination	579
C12Q1/6886	cancer diagnosis	489
A61B5/055	Electronic EMR or magnetic resonance image (MRI), such as magnetic resonance imaging	410

3.3 Funding status

The number of research projects sponsored by research grants and the total sum of the sponsorship indicate objectively the importance of individual technology themes in the big health field. This study tracked and analysed the funding support of individual technology areas of the global big health research. Table 19 demonstrates that among the 20 technology themes, the top five in terms of the volume of sponsorship are chemotherapy, diagnostic markers, environmental health, biotherapy, and infectious disease control. In terms of the volume of sponsorship from granting institutions, cancer, infectious diseases, and diseases associated with ageing receive more funding, as shown in Table 20. In general, direct therapeutic drug development in disease treatment is still the main funding theme, and chemotherapeutic and biotherapeutic drugs, represented by the treatment of cancer and infectious diseases, are the main themes receiving investment; in addition, the detection and diagnosis technologies related to ageing diseases, and the research related to environmental health improvement are also key areas of investment for big health research funds.

Table 19 | Number of funded projects and amount of funds in 20 technology themes

Tech. areas	Tech. themes	Number of funded projects	Amount of funding
Disease Prevention and Health Promotion	Movement and Sports	2,081.00	3,208.46
	Nutritional Health	25,723.00	32,857.59
	Mental Health	33,896.00	73,544.24
	Environmental Health	20,387.00	148,330.05
	Prevention Vaccine	4,008.00	69,180.16
Diseases Screening and Diagnosis	Diagnostic Markers	31,515.00	303,315.57
	Detection and Diagnosis Technology	17,359.00	34,314.08
	Basic research and Infrastructure	4,405.00	52,130.44
Disease Treatment	Chemotherapy	49,273.00	357,706.56
	Biotherapy	34,486.00	139,138.88
	Physiotherapy	3,162.00	17,018.66
	Surgical Treatment	1,545.00	9,139.08
	Complementary and Alternative Therapy	149.00	213.30
Disease Management	Nursing	1,881.00	4,469.90
	Medical Management Decisions	4,127.00	30,863.21
Public Health	Infectious Disease Control	47,331.00	93,382.03
	Food Safety	3,242.00	4,991.37
	Tobacco Control	2,238.00	3,672.78
	Health Education	688.00	478.13
	Health Service	19,300.00	47,751.22

©ANDRIY ONUFRIYENKO/GETTY

Table 20 | Top 10 Institutions for total amount of funds in individual technology themes

Fund granting institution	Total amount of funding	Tech. themes
National Cancer Institute	64,082.14	Chemotherapy
National Institute of Allergy and Infectious Diseases	61,305.74	Health Environment
National Institute of Allergy and Infectious Diseases	54,620.80	Chemotherapy
National Institute on Aging	49,024.72	Diagnostic Markers
National Institute of Allergy and Infectious Diseases	42,289.89	Infectious Disease Control
National Institute of Allergy and Infectious Diseases	40,285.55	Preventive Vaccines
National Cancer Institute	40,090.77	Diagnostic Markers
Congressionally Directed Medical Research Programs	37,260.92	Chemotherapy
National Institute on Aging	30,521.06	Chemotherapy
European Commission	28,237.97	Diagnostic markers

3.4 Analysis of technology transfer for clinical trials

This chapter provides statistics on clinical trials of chemotherapy, biotherapy, physiotherapy, surgery, and complementary and alternative therapy in disease treatment.

In terms of the number of clinical trials in different technology themes of disease treatment (Table 21), chemotherapy ranks first, indicating that various types of chemical drugs remain the main R&D area of disease treatment; biotherapies ranks second, indicating that biotechnology and bio-therapeutics are the most attractive R&D areas in recent years. In addition, clinical development of physiotherapy is gradually becoming the direction of R&D in disease treatment. In terms of China's share of global clinical trials, it shows that China contributed tremendously to clinical R&D in complementary and alternative therapy, biotherapies and surgical therapies. It is worth mentioning that China's share of clinical trials in complementary and alternative therapy reached 59.8%, as China has been vigorously promoting the R&D of Traditional Chinese Medicine (TCM).

For individual countries (Table 22), rankings in different technical directions in disease treatment also vary. The United States ranks first in chemotherapy, biotherapy, and physiotherapy, while China ranks first in surgical treatment, and complementary and alternative therapy. It is worth noting that in recent years, therapies related to emerging frontier technologies in biomedicine are mainly in the areas of chemotherapy, biotherapy and physiotherapy, with the United States still dominating in these areas in terms of the number of clinical trials. China has a significant advantage in the field of surgical treatment, and complementary and alternative therapy. In particular, China's vigorous promotion of clinical trials in TCM has ensured its leading position in this field.

©ANDREW BROOKES/GETTY

Table 21 | Number of clinical trials in disease treatment, 2016-2021

Tech. themes	Number of Chinese clinical trials	Number of global clinical trials	China's %
Chemotherapy	17,863	78,666	22.7%
Biotherapy	3,906	12,154	32.1%
Physiotherapy	1,943	10,062	19.3%
Surgical Treatment	2,627	8,691	30.2%
Complementary and Alternative Therapy	591	988	59.8%

Table 22 | Top five countries in terms of the number of clinical trials in disease treatment, 2016-2021

Tech. themes	Country	Number of clinical trials
Chemotherapy	United States	29,317
	China	17,863
	India	7,035
	United Kingdom	6,731
	Iran	6,424
Biotherapy	United States	5,260
	China	3,906
	United Kingdom	1,032
	France	925
	Germany	829
Physiotherapy	United States	2,348
	China	1,943
	Iran	881
	United Kingdom	784
	India	777
Surgical Treatment	China	2,627
	United States	2,017
	India	1,716
	Iran	709
	United Kingdom	623
Complementary and Alternative Therapy	China	591
	South Korea	85
	United States	77
	Iran	24
	Germany	21

3.5 Summary

This chapter uses patent metrics to make a quantitative analysis of the patents cited by academic papers in the field of big health, and reveals the status of technology transfer to industries.

(1) According to the analysis of patents cited by academic papers, the research on technologies in chemotherapy, infectious disease control and biotherapy have attracted the greatest attention from China and global markets, while the technologies with relatively higher technology-transfer rates are chemotherapy and prevention vaccine technologies. In addition, the analysis of patentee countries reveals that the United States attaches more importance to the technology transfer of big health research.

(2) Based on CPC classification analysis, the study of the hot technical directions of big health research shows that the industry and the research community in China and around the world are interested in the R&D of anti-tumour and anti-inflammatory drugs. The analysis of the top three technical directions in big health research, in terms of number of patents cited by academic papers, reveals that industry and the research community are interested in anti-tumour drugs, stem cells and cell engineering technology in the field of biotherapy technology; the hotspot of diagnostic marker research is machine learning-assisted imaging diagnosis. In particular, the application of medical imaging systems in cancer diagnosis and the discovery of new molecular imaging targets are the main hotspots for technology transfer.

(3) Analysis of the funding in the big health research shows that chemotherapy and biotherapy drugs represented by the treatment of cancer and infectious diseases are the main areas of investment, and the diagnostic markers related to ageing diseases and research related to environmental health improvement are also the focal areas of investment.

(4) Analysis of research output transfer of clinical trials shows that chemical drug development is still the main R&D area in disease treatment, while bio-therapeutics development became a hot R&D area in recent years. The United States has an advantage in its ability to transfer research output in chemotherapy, biotherapy and physiotherapy, while China has made more significant contributions to complementary and alternative therapy, biotherapy and surgical therapy.

Chapter 4

Comparative analysis of national research output in big health

4.1 Comparative analysis of technology areas by countries

4.1.1 Disease prevention and health promotion

In terms of the number of publications over the period of 2016-2021 in disease prevention and health promotion technologies (Table 23), the United States ranks first with 360,761 publications, followed by China with 144,894 publications. In terms of the average citation per paper for the top 10 countries, France, the Netherlands, the United Kingdom, Germany, and Italy belong to the first league. France ranks first with the average citations per paper reaching 21.85, which shows that France has a higher research impact in the field of disease prevention and health promotion technologies. In terms of the number of top 10% high quality papers, the United States ranks first with 35,134 publications, which is followed by the United Kingdom, China, Australia, Germany, and Canada, indicating that these countries have significant advantages in related research.

Table 23 | Number of publications, average citations per paper, and the top 10% publications by countries in the field of disease prevention and health promotion, 2016-2021

Ranking	Countries	Number of publications
1	United States	360,761
2	China	144,894
3	United Kingdom	105,032
4	Australia	63,169
5	Germany	59,970
		Average citations per paper
1	France	21.85
2	Netherlands	20.32
3	United Kingdom	19.97
4	Germany	18.82
5	Italy	18.59
		Top 10% publications
1	United States	35,134
2	United Kingdom	12,872
3	China	9,955
4	Australia	6,844
5	Germany	6,632
6	Canada	6,207

For patents in the field of disease prevention and health promotion technologies (Table 24), China, the United States, South Korea, Japan and Germany are the top five in terms of the number of patent applications over the period of 2001-2021, with applications in China reaching 222,644, almost 2.7 times of the number of patent applications in the United States, indicating that China has a larger presence in this field. In terms of number of patent grants, China granted 61,364 patents, the largest number compared with other countries, which is followed by South Korea (28,769). In terms of the number of patents cited by academic papers over the period of 2016-2021 (Table 25), the United States ranks first (2,972), followed by South Korea (758), Japan (460), China (253), and France (206), indicating that there is a higher level of interest in technology transfer in this field in the United States.

Table 24 | Number of patent applications and grants by countries in the field of disease prevention and health promotion, 2001-2021

Ranking	Countries	Number of patent applications
1	China	222,644
2	United States	83,452
3	South Korea	74,168
4	Japan	64,615
5	Germany	17,399
		Number of patent grants
1	China	61,364
2	South Korea	28,769
3	United States	25,281
4	Japan	9,888
5	Germany	4,513

Table 25 | Number of patents cited by academic papers by countries in the field of disease prevention and health promotion, 2016-2021

Ranking	Countries	Number of patents cited by academic papers
1	United States	2,972
2	South Korea	758
3	Japan	460
4	China	253
5	France	206

4.1.2 Disease screening and diagnosis

In terms of the number of publications over the period of 2016-2021 in disease screening and diagnosis technologies (Table 26), the United States ranks first, with 200,866 publications, which is followed by China with 135,274 publications. In terms of the average citations of the top 10 countries, the United Kingdom, Canada, Germany, France, and Italy play the leading role, with the average citations for United Kingdom reaching 20.32 times, which shows that the United Kingdom has a higher research impact in the field of disease screening and diagnosis technology. In terms of the number of top 10% high quality papers, the United States tops the list with 20,275 papers, followed by China, the United Kingdom, Germany, and the Netherlands, indicating that related research in these countries has a higher impact.

Table 26 | Number of publications, average citations per paper, and the top 10% publications by countries in the field of disease screening and diagnosis, 2016-2021

Ranking	Countries	Number of publications
1	United States	200,866
2	China	135,274
3	United Kingdom	60,433
4	Germany	50,551
5	Japan	46,071
		Average citations per paper
1	United Kingdom	20.32
2	Canada	18.77
3	Germany	18.63
4	France	18.14
5	Italy	16.85
		Top 10% publications
1	United States	20,275
2	China	8,481
3	United Kingdom	7,537
4	Germany	5,507
5	Netherlands	3,783

For patents in the field of disease screening and diagnosis over the period of 2001-2021 (Table 27), Japan, China, the United States, South Korea, and Germany are the top five countries in terms of the number of patent applications, of which Japan ranks first with 109,628 applications and China ranks second with 98,720 applications. In terms of the number of patent grants, the United States tops the list with 28,273 patent grants, followed by China with 26,160 patent grants. In terms of the number of patents cited by academic papers over the period of 2016-2021 (Table 28), the United States ranks first with 4,440, followed by Germany (1,216), South Korea (990), Japan (795), and China (225), indicating that there is a higher level of interest in technology transfer in this field in the United States.

Table 27 | Number of patent applications and grants by countries in the field of disease screening and diagnosis, 2001-2021

Ranking	Countries	Number of patent applications
1	Japan	109,628
2	China	98,720
3	United States	92,032
4	South Korea	44,775
5	Germany	25,168
		Number of patent grants
1	United States	28,273
2	China	26,160
3	Japan	19,193
4	South Korea	17,458
5	Germany	6,780

Table 28 | Number of patents cited by academic papers by countries in the field of disease screening and diagnosis, 2016-2021

Ranking	Countries	Number of patents cited by academic papers
1	United States	4,440
2	Germany	1,216
3	South Korea	990
4	Japan	795
5	China	225

4.1.3 Disease treatment

In terms of the number of research papers in the field of disease treatment over the period of 2016-2021 (Table 29), the United States ranks first in the world (349,050), and China takes the second place (242,461), followed by the United Kingdom, Japan, and Germany. In terms of average citations, France, Canada, the United Kingdom, Germany, and Italy top the list and France ranks first (23.6) indicating a higher impact of French papers in disease treatment. In terms of the number of top 10% high quality papers, the United States ranks first (35,671), followed by China, the United Kingdom, Germany and Italy, which shows that these countries have higher quality research in this field.

Table 29 | Number of publications, average citations per paper, and the top 10% publications by countries in the field of disease treatment, 2016-2021

Ranking	Countries	Number of publications
1	United States	349,050
2	China	242,461
3	United Kingdom	88,822
4	Japan	75,215
5	Germany	73,283
		Average citations per paper
1	France	23.60
2	Canada	23.01
3	United Kingdom	22.91
4	Germany	21.82
5	Italy	19.55
		TOP 10% publications
1	United States	35,671
2	China	13,887
3	United Kingdom	10,618
4	Germany	7,728
5	Italy	6,701

For patents in the field of disease treatment (Table 30), China, the United States, South Korea, Japan, and Germany are the top five countries in terms of the number of patent applications from 2001-2021, and China ranks first (165,211) and the United States takes the second place (153,276). In terms of the number of patent grants, the United States ranks first (51,536), followed by China (50,620). In terms of the number of patents cited by academic papers over the period of 2016-2021 (Table 31), the United States tops the list (11,159), followed by South Korea (1,868), Japan (1,187), Germany (1,171), and China (865), indicating that there is a higher level of interest in technology transfer in this field in the United States.

Table 30 | Number of patent applications and grants by countries in the field of disease treatment, 2001-2021

Ranking	Countries	Number of patent applications
1	China	165,211
2	United States	153,276
3	South Korea	56,586
4	Japan	54,118
5	Germany	29,509
		Number of patent grants
1	United States	51,536
2	China	50,620
3	South Korea	21,889
4	Japan	9,433
5	Germany	7,106

Table 31 | Number of patents cited by academic papers by countries in the field of disease treatment, 2016-2021

Ranking	Countries	Number of patents cited by academic papers
1	United States	11,159
2	South Korea	1,868
3	Japan	1,187
4	Germany	1,171
5	China	865

4.1.4 Disease management

In terms of the number of research papers in the field of disease management over the period of 2016-2021 (Table 32), the United States tops the list (52,853), and the United Kingdom takes the second place (23,666), followed by Australia, China, and Canada. In terms of the average citations, the Netherlands, Germany, Italy, Canada, and France are the top five countries, with the Netherlands ranking first (22.30), indicating that the Netherlands has a higher research impact in disease management. In terms of the number of top 10% high quality papers, the United States ranks first (3,517), followed by the United Kingdom, Australia, Canada, and the Netherlands, which shows that the research quality of these countries in this field is high.

Table 32 | Number of publications, average citations per paper, and the top 10% publications by countries in the field of disease management, 2016-2021

Ranking	Countries	Number of publications
1	United States	52,853
2	United Kingdom	23,666
3	Australia	12,646
4	China	9,285
5	Canada	8,792
		Average citations per paper
1	Netherlands	22.30
2	Germany	18.81
3	Italy	14.67
4	Canada	13.65
5	France	12.16
		Top 10% publications
1	United States	3,517
2	United Kingdom	1,861
3	Australia	1,302
4	Canada	953
5	Netherlands	633

For patents in the field of disease management (Table 33), China, Japan, the United States, South Korea and Germany are the top five countries in terms of the number of patent applications over the period of 2001-2021, with China ranking first (18,145) and the United States taking the second place (900). In terms of the number of patent grants, China tops the list (13,509), followed by the United States (282). In terms of the number of patents cited by academic papers (Table 34), the United States ranks first (17) from 2016-2021, followed by South Korea (6), Israel (4), the United Kingdom (2), and China (1). It is worth noting that for the nursing research in disease management, the number of patent applications and grants in China is 17,477 and 13,409, respectively, much higher than other countries, which may be related to the high priority given to the development of the nursing industry in China.

Table 33 | Number of patent applications and grants by countries in the field of disease management, 2001-2021

Ranking	Countries	Number of patent applications
1	China	18,145
2	United States	900
3	Japan	768
4	South Korea	334
5	Germany	201
		Number of patent grants
1	China	13,509
2	United States	282
3	South Korea	114
4	Germany	71
5	Japan	64

Table 34 | Number of patents cited by academic papers by countries in the field of disease management, 2016-2021

Ranking	Countries	Number of patents cited by academic papers
1	United States	17
2	South Korea	6
3	Israel	4
4	United Kingdom	2
5	China	1

4.1.5 Public health

In terms of the number of research papers in public health over the period of 2016-2021 (Table 35), the United States tops the list (327,018), and China takes the second place (123,616 papers), followed by the United Kingdom, India, and Germany. In terms of average citations, France, Germany, the United Kingdom, Italy, and Australia are the top five countries with France ranking first (22.05), demonstrating its high research impact in public health. In terms of the number of top 10% high quality papers, the United States ranks first (34,010), followed by the United Kingdom, China, Germany, and Canada, indicating that these countries have higher quality research in this field.

Table 35 | Number of publications, average citations per paper, and the top 10% publications by countries in the field of public health, 2016-2021

Ranking	Countries	Number of publications
1	United States	327,018
2	China	123,616
3	United Kingdom	84,634
4	India	56,127
5	Germany	42,972
		Average citations per paper
1	France	22.05
2	Germany	20.64
3	United Kingdom	19.76
4	Italy	19.59
5	Australia	18.13
		Top 10% publications
1	United States	34,010
2	United Kingdom	10,962
3	China	9,118
4	Germany	5,135
5	Canada	5,086

For the patents in the field of public health (Table 36), in terms of the number of patent applications from 2001 to 2021, China, the United States, South Korea, Japan and Germany are the top five countries, with China ranking first (128,306), followed by the United States (72,069). In terms of number of patent grants, China tops the list (46,662), followed by the United States (21,625). In terms of the number of patents cited by academic papers over the period of 2016-2021 (Table 37), the United States ranks first (3,196), followed by South Korea (437), Germany (222), China (215), and France (186).

Table 36 | Number of patent applications and grants by countries in the field of public health, 2001-2021

Ranking	Countries	Number of patent applications
1	China	128,306
2	United States	72,069
3	South Korea	22,566
4	Japan	20,744
5	Germany	8,050
		Number of patent grants
1	China	46,662
2	United States	21,625
3	South Korea	8,163
4	Japan	2,660
5	Switzerland	1,939

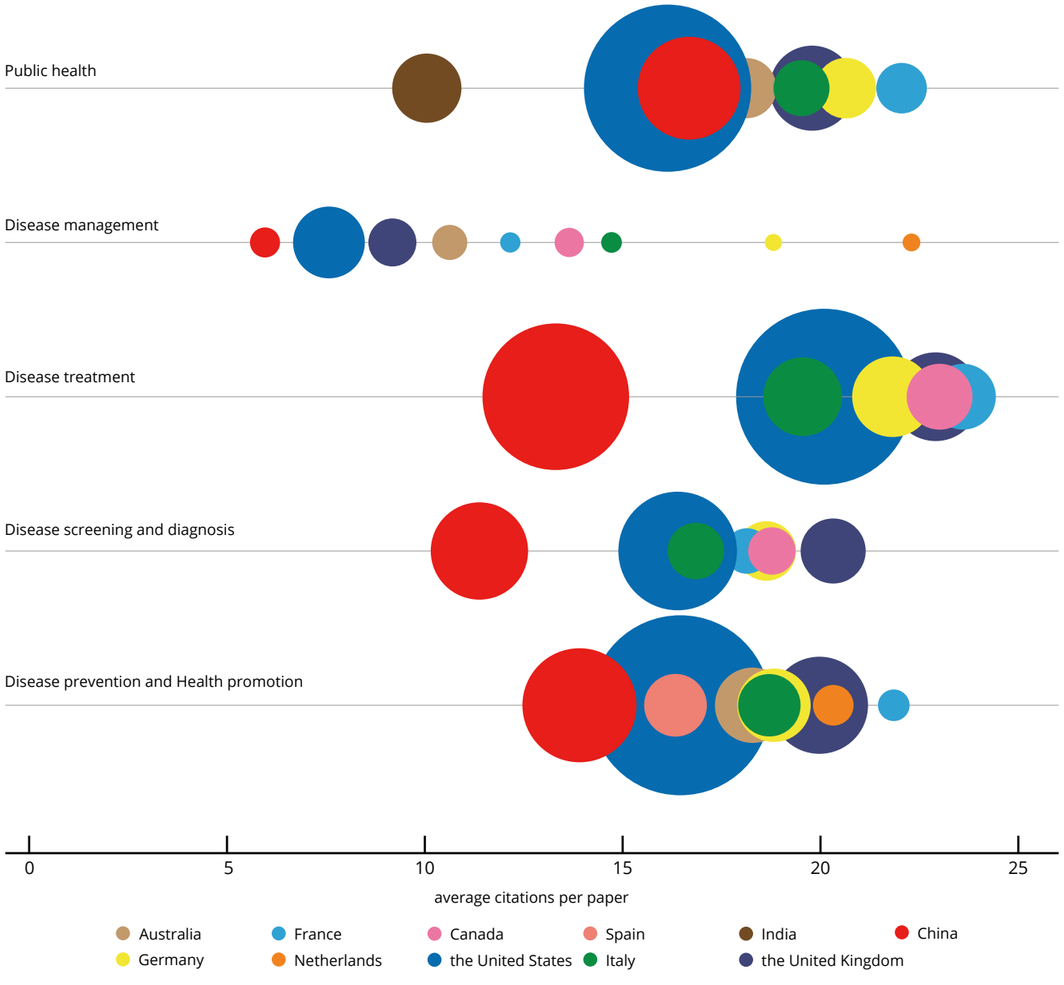
Table 37 | Number of patents cited by academic papers by countries in the field of public health, 2016-2021

Ranking	Countries	Number of patents cited by academic papers
1	United States	3,196
2	South Korea	437
3	Germany	222
4	China	215
5	France	186

4.2 Overall comparison of topics by countries

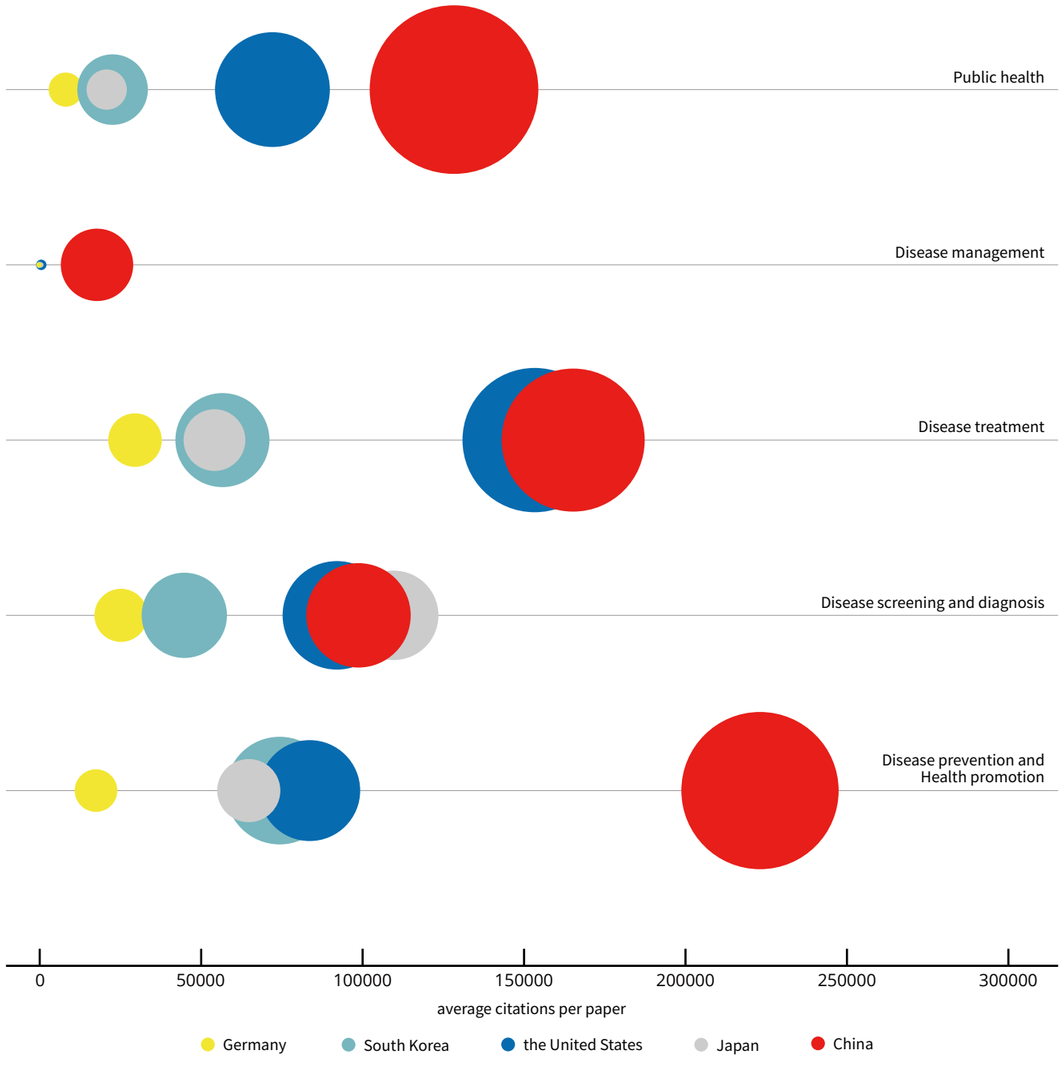
In terms of research activity (number of publications) and research impact (average citations per paper) in the five technology areas of big health research (Figure 6), the United Kingdom and Germany enter the top five in four of the five technology areas, reflecting a comprehensive coverage and strong research strength of these countries in the field of big health. In terms of research activity, the United States leads in the number of research papers published in all five technology areas, especially in public health, disease prevention and health promotion, while China follows closely in the number of publications in disease treatment. In terms of research impact, the United Kingdom, France, and Germany entered the top three in terms of average citations in three of the five technology areas, while China is down the country ranks in this regard in four of the five technology areas, which needs to be further boosted.

Figure 6 | Benchmarking of China and the top 10 countries (excluding China) in terms of the number of publications and average citations in individual technology areas



In terms of the number of patent applications and grants by countries in the five technology areas of the big health research (Figure 7), China, the United States, Japan, Germany and South Korea are in the top five in all five technology areas, indicating that these countries have considerable strength in the technology transfer of related research output. In terms of the number of patent applications and grants, China is in the leading position in four of the five technology areas of big health research, and China has significant advantages especially in disease prevention and health promotion, public health, and disease management.

Figure 7 | Benchmarking of China and the top five countries (excluding China) in terms of the number of patent applications and grants



©YUICHIRO CHINO/GETTY

4.3 Summary

This chapter analyses the research publications and patents in the field of big health to reveal its research output.

(1) In terms of total number of research publications and high quality papers in the five technical areas, which are disease prevention and health promotion, disease screening and diagnosis, disease treatment, disease management, and public health, the United States ranks first, and there is a higher level of interest in technology transfer in related fields in the country. In the field of disease prevention and health promotion, France has a higher research impact, and China ranks first in terms of total number of patent applications and grants. In disease screening and diagnosis, the United Kingdom has a higher research impact, and Japan ranks first in terms of the number of patent applications, while the United States ranks first in terms of the number of patent grants. In disease treatment, Canada has a higher research impact, while China tops the list in terms of the number of patent applications, and the United States ranks first in terms of patent grants. In disease management, the Netherlands has a higher research impact, and China tops the list in terms of the number of patent applications and grants. In public health, France has a higher research impact, and China ranks first in terms of the number of patent applications and grants.

(2) From the perspective of research output in the five technology areas, the United Kingdom and Germany have comprehensive deployment and strong research strength in the field of big health, and the United States has obvious advantages in public health, disease prevention and health promotion. China, the United States, Japan, Germany and South Korea have strong ability to transfer research output in the field of big health, and China is in the leading position in terms of the number of patent applications and grants in four of the five technology areas, especially in disease prevention and health promotion, public health and disease management.

Chapter 5

Interviews in key research areas

©WESTEND61/GETTY

The big health industry involves biotechnology, nanotechnology, information technology, and advanced manufacturing technology. As an interdisciplinary industry, it's integrating more research fields. As a typical technology-intensive industry, its high- quality development lies in giving full play to the leading role of scientific and technological innovation. A comprehensive analysis of the global technology status of the big health industry shows that the growth in the number of global publications and the quality improvement of these publications fully reflect the research community's intense interest and the R&D investment in basic research.

Aiming to meet increasing demand for health, the big health industry, based on the development of life sciences and biotechnology, takes the advantages of the scientific and technological innovation empowered by digital technologies such as big data and artificial intelligence, and undergoes continuous updates in the technological innovation and industrial pattern. This is mainly reflected in the following aspects. (1) The focus of future medicine shifts from disease treatment to disease prevention; (2) disease diagnosis is becoming more precise, more portable and more intelligent; (3) new technology drives the paradigm shift in innovative drug development; (4) the construction of public health, health management and service system is empowered by big data and artificial intelligence. Several factors have been constantly driving the high quality and sustainable development of the big health industry, such as the frequent release of policies in the field of big health, the increasing investment in key areas, the acceleration of R&D in cutting-edge technologies and applied technologies, and the continuous increase of the strategic value of biomedicine and the big health industry.

5.1 Focus of future medical research is shifting from disease treatment to disease prevention

Novel vaccine technologies have become a way to address future global health challenges. The outbreak of COVID-19 pandemic has highlighted the importance of developing innovative vaccine technologies, with those such as mRNA vaccines becoming an important tool for epidemic prevention and control. From traditional vaccines such as inactivated vaccines and attenuated vaccines to new vaccines such as DNA vaccines and RNA vaccines, technologies have evolved from the 'isolation, inactivation and injection' of pathogens to modern vaccine technologies integrating genetic engineering, immunology, structural biology, reverse vaccinology and system biology. The development of future vaccine technologies lies in adjuvant technologies, drug delivery system, and new vaccine design technologies. In addition to prevention vaccines, therapeutic vaccines for chronic diseases such as cardiovascular diseases and tumours have also become a research hotspot. Therapeutic vaccines are biologics constructed from antigenic determinant peptides and vectors to identify the specific target molecules of the body system, and the immune body system would induce specific antibodies against their own target antigenic determinant and exert therapeutic effects on the target molecules. Compared with traditional chemical drugs, therapeutic vaccines have the advantages of high specificity and long period of acting time. For the time being, several therapeutic vaccines are in the clinical stage.

Meanwhile, precision medicine can help prevent diseases and promote health. It can advance early diagnosis and treatment of diseases, as well as early warning and prediction. Shifting the focus to the community level may promote health management. Specific measures include conducting population cohort studies through big data to secure different disease diagnosis and treatments and health management measures for different population groups with distinctive characteristics so as to improve their overall health and reduce medical costs. Through the detection of disease susceptibility genes and early intervention to adjust daily life and medication habits, we can develop personalized screening programmes for people with different genetic risks, in different age groups and in different environments, and improve the efficiency of disease screening, avoid excessive screening, and customize intervention strategies based on the disease detection results.

At the same time, intelligent health management devices will facilitate accurate health management. The growing popularity of individualized health management concept and the wide application of mobile technology have promoted the use of intelligent health management devices, such as wearable devices in disease monitoring, rehabilitation and home care. At present, intelligent health management devices mainly mean limb assistive devices that help patients with physical disability to carry out rehabilitation training, non-invasive diabetes monitors that help patients monitor and evaluate blood sugar levels in real time, and Parkinson disease monitors. At present, this technology still faces technical difficulties in the accuracy and reliability of data analysis, and identification of complex diseases, but it has gradually moved from the lab to actual applications , and will become an effective tool for health management in the future.

©ANDRIY ONUFRIYENKO/GETTY

5.2 Disease diagnosis is becoming more precise, more convenient and more intelligent

Sequencing technology is the cornerstone of accurate diseases diagnosis. Along with the further advancement of genome research and the development of high-throughput sequencing technology, a series of major international programmes have been initiated, such as the Human Genome Project (HGP) and the U.S. Human Microbiome Project, with which we have acquired new understanding of life. Next-generation sequencing technology, a cornerstone for precision medicine, can efficiently build a genomic database with a large sample size and interpret the data together with individual clinical data to discover the correlation between genes, diseases and medication. This is helpful for clinics to provide precise and reasonable disease prevention and intervention, diagnosis and treatment, medication guidance and health management for individuals. In the process of combating COVID-19, the second-generation sequencing technology based on metagenomics has played a crucial role in pathogen detection. For the future applications, the major constrains of precision diagnosis mainly include technological innovation in detection speed, application scenario and detection cost of sequencing technology, as well as the ethical and social issues of sharing and standardization of large amount of individual biological data.

Meanwhile, miniaturization and portability of devices are expanding the application scenarios of disease diagnosis. With the evolution of the testing technology, clinical laboratories are heading for automated and simplified operation, and portable medical instruments and rapid diagnostic technologies represented by point-of-care testing (POCT) have brought new development opportunities for medical pattern. In addition to the most widely used immunochromatography assay technology, dry chemistry technology, microfluidics technology, portable sequencers and medical imaging devices are on the market, such as portable ultrasonic diagnostic instruments, portable X-ray machines, and hand-held DNA sequencers. In addition, a network is being formed by the integration and analysis of the rapid testing results and the collected data from the terminal devices and cloud medical resources, to build a real health management system for future disease diagnosis.

Digital innovation is also driving the development of intelligent disease diagnosis. The rapid development of artificial intelligence and other digital technologies has laid the foundation for the development of various computer-aided diagnostic systems, and the application of a large number of new strategies and algorithms has facilitated the 'quantitative' forward movement of disease diagnosis to realize early warning, assessment, and intervention. Many experiments have shown that the application of artificial intelligence in disease diagnosis significantly improves the accuracy and efficiency of disease diagnosis. Computer-aided image diagnosis technology involves the following key steps, such as acquiring medical image samples, setting up initialized models, machine learning, and pathological image analysis. The future development lies in establishing a large data centre with large standardized samples, engaging in distributed parallel training of ultra-large scale data and complex deep patterns, and using the application results as the target driver.

5.3 New technologies are driving the changes in innovative drug development pattern

Multidisciplinary integration promotes continuous innovation in biotechnology, especially in biomedicine. Currently, the biomedical field has established itself as the frontier area to lead the development of 'convergence' paradigm. It has become more systematic and integrated engineering and digital technologies. A number of frontier research fields have emerged, such as synthetic biology, life omics, systems biology, nanobiology, and brain science, which are supported by different disciplines, such as medicine, biology, engineering, computer, robotics, physics, materials science, and chemistry. In addition, many frontier technologies have come into shape, such as omics technology, drug molecular design technology, molecular imaging technology, engineering organoid, high-throughput detection technology and many other cutting-edge technologies. These technologies and tools in turn can promote life sciences research from macroscopic to microscopic, and bring breakthroughs in life sciences research, biotechnology development, and biomedical industry.

Meanwhile, drug development is shifting from being hypothesis-driven to data-driven. This is jointly promoted by advances in data science and analytics technologies represented by omics technology, artificial intelligence and cloud technologies, the establishment of real-world data ecosystems, and the accelerating collaboration between pharmaceutical companies and healthcare systems and data startups. The application of data analytics technologies such as artificial intelligence can make it faster and easier to develop targeted drugs for specific groups; cloud technologies can help standardize data from various platforms and sort out unstructured data types; various data exchange programmes effectively promote innovative data sharing between pharmaceutical companies and regulatory agencies, thus improving the efficiency of the regulatory process and shortening the wait for innovative drugs.

Another new technology is cell and gene therapy (CGT). Innovative therapies such as cell and gene therapies provide new treatment options for incurable diseases such as tumours and genetic disorders. These therapies have become a focus in the global context. Though expensive, cell and gene therapeutic drugs have very good efficacy. With upstream fast-track administrative approval and downstream insurance support, cell and gene therapeutic drugs are increasingly allowing commercialization, with demand constantly rising. At the same time, cell and gene therapeutic drugs are highly individualized. They tend to have more adverse reactions, and impose higher requirements for clinical trials, which brings new challenges for product development, clinical treatment, marketing and supervision of the whole production process.

There are new strategies to improve drug discovery and development, such as antibody conjugation, targeted protein degradation (TPD), and radio pharmaceutical, which have greatly increased the possibility of developing innovative drugs. Taking protein degradation targeted chimeras (PROTAC) as an example, this type of drugs use ubiquitin proteasome pathway to degrade target proteins and solve the 'undruggable' problem and the issue of resistance to small molecule drug target. This has revolutionized drug development in this field. Global pharmaceutical giants, including Roche, GlaxoSmithKline and Sanofi have started strategic planning in this regard. Currently, these new drug development strategies have played an important role in drug development for oncology, infectious diseases, and neurological diseases, and there are a number of products under development.

Another important tool for drug development and evaluation is organ-on-a-chip technology, which ends the limitations of cell culture and animal models. Based on various technologies such as microfluidic chip, microfabrication, stem cell, material and biological tissue engineering technologies, a 3D human organ model is built by in vitro simulation, which contains a variety of living cells, functional tissue interface, and biofluid. The model has physiological functions close to that of human organs. It also enables precise control of multiple system parameters, allowing researchers to intuitively observe and study the organ's reaction and predict or reconstruct the effects of drugs, toxins, radiation, pathogens and microbiome changes. It has promising applications in life sciences research, disease simulation and new drug development, and precision medicine. In August 2022, the U.S. Food and Drug Administration (FDA) approved an investigational therapy to enter clinical trials, an important milestone for development of the organoid, and the approval is based entirely on preclinical efficacy data obtained in human organ-on-a-chip studies.

5.4 Big data and AI empower the construction of public health, health management and health service systems

Big data promotes the accurate management of major health emergencies, allowing public health departments to quickly monitor infectious diseases through a nationwide electronic medical case database, and respond swiftly through an integrated disease surveillance and response mechanism. In combating the COVID-19 pandemic, big data plays a crucial role in regular surveillance, early warning, trend prediction, tracing the source of infection, resource allocation, and prevention and treatment. At present, the United States, the United Kingdom, Japan and other developed countries have built a more sophisticated big data platform in healthcare, and are engaging effective management and technology upgrading. President Xi Jinping made important remarks on disease prevention system and major epidemic prevention and treatment system at the 12th session of the Central Committee for Comprehensively Continuing Reform, and made it clear that China should 'encourage the use of big data, artificial intelligence, cloud computing and other digital technologies for better epidemic monitoring and analysis, virus tracing, prevention and treatment, and resource allocation.' Therefore, the full use of big data technologies and methods is of far-reaching significance to accelerate the improvement of China's public health system.

The establishment of a unified health information standard system should also be accelerated. Standardized health information is fundamental for the development of digital technologies such as big data and artificial intelligence. In 2020, the National Health Commission of the People's Republic of China issued the *Opinions on Strengthening the Construction of the Standardization System of Health Information* to promote standardization of public health, community level healthcare and other information systems to realize data integration and sharing among regions. In addition, the establishment of health information standard systems also helps promote the classification and grading of healthcare data and its open applications, and promote the pilot application of medical artificial intelligence in intelligent clinical aid treatment, medical robotics, AI drug development, intelligent public health service, hospital management, medical devices management, as well as intelligent medical education.

Remote clinical service should also be developed to enhance accessibility. It refers to the use of modern information and telecommunication technology to transmit data, voice, images and other information in both directions as a means to provide long-distance medical services, including remote diagnosis, remote consultation, remote nursing, and remote education. Due

to the COVID-19 pandemic, the demand for remote clinical service has increased. The development of this kind of service is beneficial to improving the accessibility of medical resources, lowering medical costs, and enhancing efficiency. The technologies related to remote clinical service include hardware technologies such as high-definition screens, microphones and high-definition cameras to support video and audio communications, software such as health information systems (HIS), electronic medical records and referral platforms, and communication technologies such as 5G communication networks. In addition, the integration of block chain, artificial intelligence and Internet of Things also reinforces the security of this service, improves operation efficiency, and expands application potential.

Meanwhile, the use of robots makes public health service more intelligent and more automatic. During the pandemic, many businesses used touch-free transaction and long-distance service to maintain operations, and it is the new normal. The pandemic has driven the digital transformation of industrial manufacturing, and at the same time witnessed the huge role of artificial intelligence and robotics in healthcare and public services. The technology updates and new innovations, such as artificial intelligence chips, and advanced sensors, have constantly improved the performance and intelligence of robotic products. Continuous technology breakthroughs in machine vision, speech recognition, and deep learning have empowered service robots with increasingly stronger capabilities in image recognition, language communication and emotional exchange, and their application scenarios and service modes are constantly expanding. At present, robots can complete assistive and service tasks in multiple scenarios from purifying and sterilizing work, food and drug delivery, assisting medical personnel in monitoring vital signs, rehabilitation training, and immigration control.

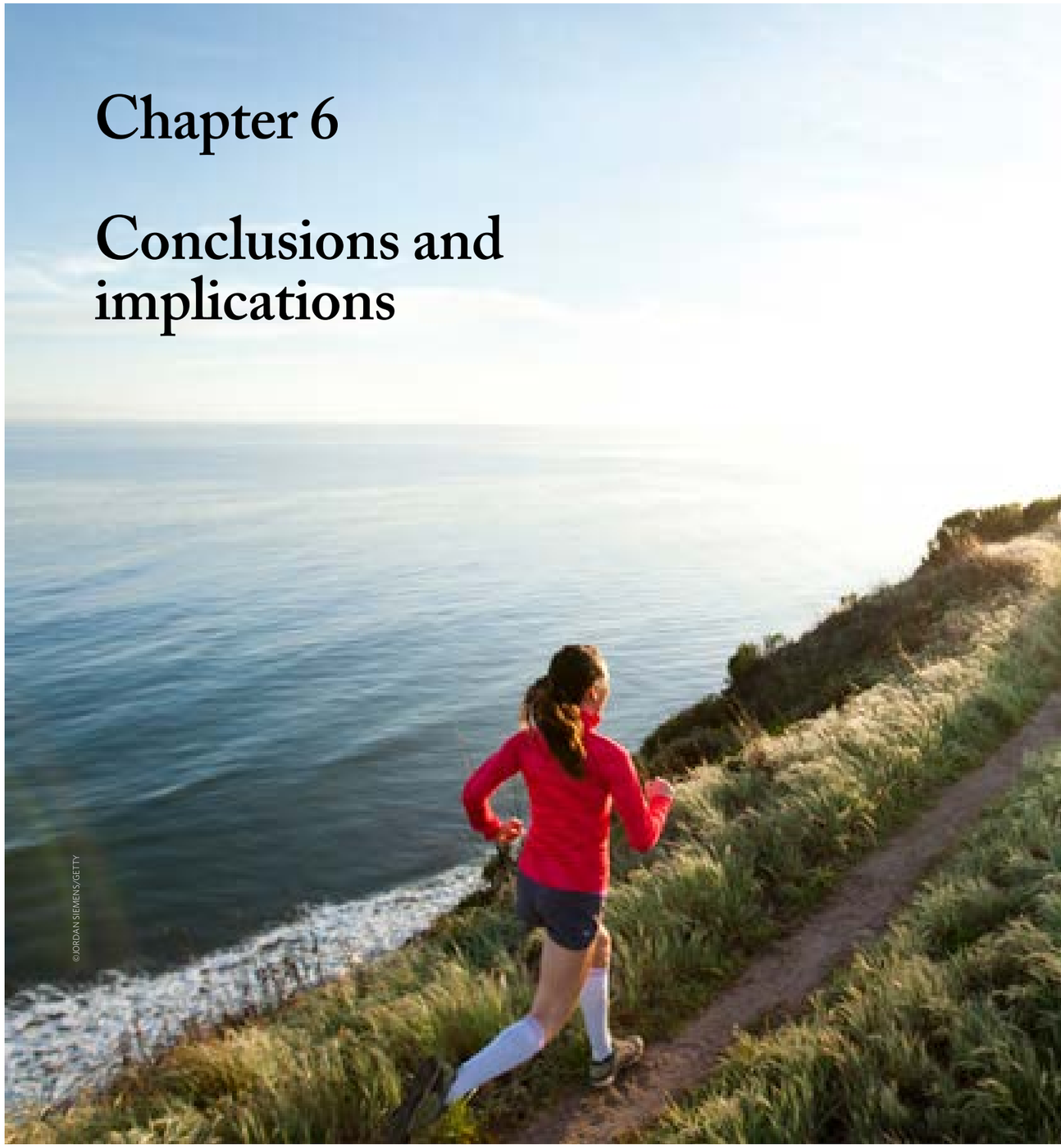
The scenarios for smart care are also expanding. Technologies such as the Internet of Things, big data, cloud computing, artificial intelligence and 5G continue to improve smart care in an innovative way, which makes it possible to provide more professional daily care, medical services, rehabilitation care, health checkups, emergency rescue to the elderly. In terms of research and development of products, the one-button lift chair to assist toilet use, contactless health monitoring devices combined with nanoscale biosensors, automatic nanotech bubble bathing machine, furniture with intelligent interaction function, to name just a few, have greatly improved the quality of daily life for the elderly. For the construction of data information platform, the big data information platform provides strong support for the continuous refinement of smart care services. The integration of information resources and intelligent outbound call system can provide a full-coverage, normalized and smart care mechanism for the elderly living alone.

Today, the safe use of data has become an integral part of the development of the healthcare industry. In recent years, countries around the world have strengthened the regulation of the circulation and use of personal healthcare data, and put in place many relevant legal provisions and restrictions. The safe use of data has become an important part of the healthcare industry. In order to promote the circulation, use, transaction and value presentation of big data in medical and healthcare amid strong regulation, and unswervingly promote the specific IT technology innovation and applications, privacy-preserving computing technology enters a period of flourishing development, such as multiparty secure computing, federated learning, distributed computing, sandbox computing, which are based on cutting-edge IT technologies such as the block chain with the characteristics of decentralization, data validation, data source traceability and original data immutability. These technologies ensure the regulatory requirement of 'data available but not visible', and are used to explore the circulation mechanism of big data in medical and healthcare, and the technical materialization pathways in a law-abiding way. In the future, taking laws and regulations, and socio-economic aspects into consideration will be the norm for biomedical big data applications and technology transfer in countries around the world, which will play a critical role in realizing the value of healthcare data, and bring a significant impact to the development of healthcare industry in the digital era.

©WESTEND61/GETTY

Chapter 6

Conclusions and implications



©JORDAN SIEMENS/GETTY

6.1 Conclusions

Due to the impact of the COVID-19 pandemic, global big health research is embracing a golden age of accelerated development, and the academic impact of Chinese scholars is on the rise. Researchers worldwide published more than 3.29 million academic papers in five big health technology areas over the period of 2017-2021, including disease prevention and control, disease screening and diagnosis, disease treatment, disease management, and public health, indicating that big health technologies research has become a global hotspot. To be specific, China's share reaches 16.7% against the number of global publications, and the impact of Chinese papers is higher than the global average, clearly demonstrating the rapid development of big health research in China. In addition, disease treatment, disease prevention and health promotion, and disease screening and diagnosis are the top three technology areas in terms of the number of global publications in the past five years, while chemotherapy, surgical treatment, and infectious disease control are the top three most promising technology themes in the world.

The technology transfer rate is relatively high in some areas of big health research, but the deep integration of the industry and the research community needs to be strengthened. In terms of the proportion of academic papers cited by patents against the total number of publications in the field of big health research, chemotherapy, prevention vaccine and biotherapy technology enjoy relatively high technology transfer rate, while the R&D of anti-tumour and anti-inflammatory drugs is a technology hotspot across the world. In the global context, the United States has a dominant position in research output transfer in chemotherapy, biotherapy, and physiotherapy, while China has made more significant contributions in this regard in complementary and alternative therapy, biotherapy, and surgical therapy.

The technological achievements in the field of big health mainly come from the top countries, but there are significant differences in the efficiency of research output. In terms of the number of publications, China ranks in the top three countries in all five technology areas, indicating a high level of research activities in these major areas of the big health research. In terms of research impact (average citations and number of high-quality research papers), China ranks in top five in four of the five technology areas, but China is relatively lower down the global rankings in most technology areas in terms of average citations, indicating that China's efficiency needs further improvement. In contrast, the United Kingdom and Germany have higher research efficiency big health research, and their total number of publications and research impact are more balanced, ranking in top five in four of the five big health technology areas.

Finally, the focus of medical research will shift in the future, and digital technologies such as big data and artificial intelligence will drive technological changes and upgrades in the big health industry. The future focus of medicine will shift from disease treatment to disease prevention, and new technologies, such as novel vaccines, precision medicine, intelligent health management devices, will further strengthen the development of disease prevention and health promotion in the field of big health. The development of new generation information technology makes disease diagnosis more precise, more portable and more intelligent, while the deep integration of biotechnology and information technology will not only drive the paradigm shift in drug development, but further improve the level of public health service.

6.2 Implications

Disease prevention and health promotion is the direction of development and ultimate goal of big health research. Prevention is the most economical and effective health strategy, and promoting whole-life health management is among the practical needs of disease prevention and health promotion in the new era. In addition, scientific and technological innovation is indispensable for the development of key technologies such as preventive vaccines. China should further refine its strategy in movement and sports, nutritional health, mental health, environmental health and preventive vaccines. China should be more forward-looking in disease prevention, promote the comprehensive integration of scientific and technological innovation, and devote efforts to promoting the transfer and application of research output.

Disease screening and diagnosis is the basis for the development of the big health industry. Due to the impact of the COVID-19, the rapid development of biotechnology and the strong support by national policies, disease screening and diagnosis has become an important growth point to boost the big health industry. Detection and diagnosis technology, a sub-category technology theme in the area of disease screening and diagnosis, has higher technology transfer rate in the field of big health, and diagnostic markers, in particular, play a key role in the development of detection and diagnosis technology. China should accelerate research on medical markers that can be used for disease diagnosis, prediction, early warning and efficacy evaluation, and strengthen the development of new technologies and products for disease screening and diagnosis to achieve breakthroughs in accuracy, automation, intelligence and portability.

Further, technology development in the field of disease treatment is an important guarantee to promote the development of the big health industry. As the key technology themes of disease treatment, chemotherapy and biotherapy are the focuses of developed countries. Small molecules drugs are still dominating the development of drugs for disease treatment. With the integration of biotechnology and information technology, artificial intelligence and computer-aided drug development is becoming

©SOLSKIN/GETTY

the mainstream. Major breakthroughs are expected to be made in PROTAC technology, allosteric modulator and deuterated drugs. With policy support, the frontier technologies of biotherapy, such as stem cells and regenerative medicine, immunotherapy, cell and gene therapy, are becoming increasingly active in innovation, and scientific achievements are emerging at an accelerated pace. China should strengthen research on new small molecule drugs such as PROTAC and key technologies of innovative therapies such as cell and gene therapy. It should also apply big data, artificial intelligence and other technologies in drug development, accelerate the clinical application of cutting-edge technologies for disease treatment, and improve clinical treatment.

At last, scientific and technological innovation will be key to tackling major health challenges. The new round of scientific and technological revolution and industrial transformation is accelerating. The integration of new generation information technology such as 5G and big data with the big health field, and its innovative development provide scientific and technological support for the development of public health. In particular, researchers around the world have conducted in-depth research and made a series of important scientific achievements in addressing global public health security challenges, infectious disease control, and tobacco hazards. China should strengthen international cooperation in scientific and technological innovation in the field of public safety, actively conduct international joint research in infectious disease control, food safety, tobacco control, health education and health service, and establish a scientific and technological innovation system capable of rapid response and open for collaboration. China should also continue to apply digital technologies such as the Internet, big data, artificial intelligence and block chain in the public health service system, establish a digital traceability system for food and drugs and other related products, develop digital medical care and mobile medical care, and accelerate intelligent development in disease prevention, clinical decision-making, health management, and hospital management.

中国科学院科技战略咨询研究院
Institutes of Science and Development, Chinese Academy of Sciences

Phone:+86(0)10 59358691
Email:linhui@casisd.cn
Website:www.casisd.cn

中国科学院上海营养与健康研究所生命科学信息中心
Shanghai Information Center for Life Sciences, Shanghai
Institute of Nutrition and Health, Chinese Academy of Sciences

Phone:+86(0)21 54922897
Email:kymao@sinh.ac.cn
Website:www.sinh.cas.cn