BASIC MEDICAL SCIENCES / TEMEL TIP BİLİMLERİ

Descriptive and Predictive Analysis of Artificial Intelligence Research and Innovation in Health

Sağlık Alanında Yapay Zeka Araştırma ve İnovasyonunun Tanımlayıcı ve Öngörücü Analizi

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Abstract

Objectives: The aim of this study is to assess the research and innovation status of artificial intelligence (AI) in health sciences with a special focus on different application areas in health sciences and start-ups companies.

Materials and Methods: Here in, two different datasets were used for analysis. The Web of Science database was analyzed to examine the scientific and technological knowledge production of AI technology in the health sector in general and in predetermined application areas. Secondly, the database of the technological investment portal dealroom.co, which includes innovative start-up organizations that produce AI-based solutions in the field of digital therapeutics and healthtech, was investigated.

Results: In terms of contribution to AI-related literature, the USA and China lead in AI-focused publications, while Germany (22.2%) and the USA (21%) have the most health-specific coverage. Italy, Canada and the England follow these countries respectively (13.8%). Türkiye's rate was found to be 10.1%. On the other hand, the United Kingdom (n=24) and Israel (n=21) stand out in terms of AI-powered start-ups in the health sector. Türkiye stands in the top ten countries distributing to AI-powered health science research but has no companies in the same field.

Conclusion: AI in healthcare is on the rise, driven by increased research and applications, especially during the coronavirus disease-2019 pandemic. Some health subtopics remain underexplored, but start-ups are making promising strides. Wider AI adoption in healthcare is expected as financial and regulatory challenges are addressed.

Key Words: Artificial Intelligence (AI), healthcare sector, healthcare research

Öz

Amaç: Bu çalışmanın amacı, sağlık bilimlerinde ve start-up şirketlerinde farklı uygulama alanlarına odaklanarak sağlık bilimlerinde yapay zekanın (AI) araştırma ve yenilik durumunu değerlendirmektir.

Gereç ve Yöntem: Bu çalışmada analiz için iki farklı veri seti kullanılmıştır. AI teknolojisinin genel olarak sağlık sektöründe ve önceden belirlenen uygulama alanlarında bilimsel ve teknolojik bilgi üretimini incelemek amacıyla Web of Science veri tabanı analiz edildi. Ardından, dijital tedavi ve sağlık teknolojileri alanında AI tabanlı çözümler üreten yenilikçi start-up organizasyonlarının yer aldığı teknolojik yatırım portalı dealroom.co'nun veri tabanı analiz edildi.

Bulgular: AI ile ilgili literatüre katkı açısından, AI odaklı yayınlarda ABD ve Çin başı çekerken, sağlığa özel yayınlarda en fazla Almanya (%22,2) ve ABD (%21) yer alıyor. Bu ülkeleri sırasıyla İtalya, Kanada ve İngiltere (%13,8) takip etmektedir. Türkiye'de ise bu oran %10,1 olarak belirlendi. Öte yandan sağlık sektöründe AI destekli start-up'lar açısından Birleşik Krallık (n=24) ve İsrail (n=21) öne çıkıyor. Türkiye, AI destekli sağlık bilimi araştırmalarını paylaşan ilk on ülke arasında yer alıyor ancak aynı alanda şirketi bulunmuyor.

Sonuç: Sağlık hizmetlerinde AI, özellikle koronavirüs hastalığı-2019 salgını sırasında artan araştırma ve uygulamaların etkisiyle artıyor. Bazı sağlık alt konuları hala yeterince araştırılmıyor ancak start-up'lar umut verici ilerlemeler kaydediyor. Finansal ve mevzuatla ilgili zorluklar çözüldükçe sağlık hizmetlerinde AI'nın daha geniş çapta benimsenmesi bekleniyor.

Anahtar Kelimeler: Yapay Zeka (AI), sağlık sektörü, sağlık araştırmaları

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Introduction

Artificial intelligence (AI) is a technology with such profound impacts that it stands as a contender for heralding the dawn of a new era. Like the era-defining technologies that preceded it (the steam engine, semiconductors, the internet, recombinant DNA technology, nanoscale material handling, etc.), it has emerged with existing know-how, but is poised to impact and irreversibly change all areas of societies, products and commerce, including its predecessor technologies (1). The achievements of AI technologies, which are by nature a distruptive and ground-breaking innovation, and today have gained popularity with various end-user applications and have either impacted or are being developed in almost every field including healthtech. Even though the first term of AI was used in 1956, the emergence of machine learning methods accelerated the application of AI in medicine as in all other areas of life (2). One of the most important outcomes that AI brings to healthcare is the cost savings that result from focusing on health management rather than treatment, which can reduce hospitalizations, doctor visits, and treatments (3).

Although there are publications about the potential effect (4,5) and reports about the future market (6) of AI on health sector, there is a paucity of information in the literature about which of the areas in health sector and what kind of applications in a healthcare system are currently being studied, developed or inovated in a more comprehensive and encompansating way. Thus, in this research, it is aimed to analyse the AI in health technologies in terms of publication topics and types, focused technological and technical application areas in health systems (diagnosis, drug, treatment, therapy, surgery, healthcare), innovations (in digital therapeutics and healthtech) and trends [including the effect of coronavirus disease-2019 (COVID-19) pandemic]. In order to reach these goals, scientific and enterprise datasets were analyzed and some solid evidences were obtained about the current/future concentration of AI technology in health. In addition, concentrated and currently untouched areas of knowledge generation in subtopics of health - with a specific attention to biotechnology-related areas since its the former technological breakthrough in health - for the first time in literature, which will pave the way to the researchers aiming to study in this field.

Materials and Methods

Source, Quality, and Quantity of Collected Datasets

Within the scope of the study, two different datasets were used for analysis. The Web of Science (WoS) database was analyzed to examine the scientific and technological knowledge production of AI technology in the health sector in general and in predetermined application areas (7). Secondly, the database of the technological investment portal dealroom.co, which includes innovative start-up organizations that produce AI-based solutions in the field of digital therapeutics and healthtech, was analyzed (8). The results obtained by searching "artificial intelligence" as a topic in the WoS database were compiled based on the parameters of country, WoS categories (for the selection of the category in the field of health), year and citation topics meso (an algorithm developed by Clarivate InCites that determines the topic addressed through the dynamic and mutual citations of articles) (9). In addition, the approaches before and after the COVID-19 pandemic were examined by analyzing AI searches in the field of health through Google Trends (10).

Statistical Analysis

Tabulation, geographical and graphical data representation were performed in Excel 2021 (Microsoft, Redmond, WA, USA) program. Sankey diagram for visualizing the connection between citation topics meso and the focused application areas in heath sector was graphed in Power BI version 2.120 (Microsoft, Redmond, WA, USA) program with Sankey 3.1.2 visualization patch. Forecasting analysis for revealing the effect of COVID-19 pandemic on sentiment analysis of society about interest in AI in health sector was processed in SPSS version 24.0 (IBM, Armonk, NY, USA) program with Expert Modeler function. Details and working principle of forecasting analysis with SPSS can be found in the technical documentation of the program (11).

Results

Mapping the Global Landscape of AI Research Contributions

The initial study aimed at examining the utilization of AI technology in the healthcare sector involved the assessment of research articles across different countries. The results of the research conducted in the WoS database under the topic of "artificial intelligence" were filtered by research article and country, uncovering the nations actively participating in generating knowledge and contributing value in this domain.

Here in the Figure 1, the top 20 countries with the highest number of research articles are visualized geographically and their publications are visualized in terms of the number of articles. In this ranking, where Türkiye is the 16th country with the highest number of publications, it is observed that the USA and China take the first two places significantly compared to other countries.

In the continuation of the research, all publications listed in the WoS database from Türkiye and the top 10 countries in

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Figure 1 were classified by WoS category; 1) categories that are directly related to the field of health (Figure 2a, blue bars) and 2) peripheral categories - genetics, microbiology, etc. - that are not directly related to the field of health but whose outputs can be used in this field or where health-related publications can be included under the same title (Figure 2a, orange bars) and their proportions in total publications were determined. As a result of the analysis, it was determined that Germany (22.2%) and the USA (21%) are the countries that focus the most on AI publications in the field of health. Italy, Canada and the UK follow these countries respectively (13.8%). Türkiye's rate was found to be 10.1%.

In the rest of the study, the total number of articles in the health fields included in the WoS categories were analyzed. The health fields that have published more than 500 AI articles worldwide are listed in Figure 2b. A total of 13 fields were identified and the highest number of AI articles was found in the field of "Radiology Nuclear Med. & Imaging" (2.357). "Medical Informatics" (1.688), "Medicine General Internal" (1.494),

"Health Care Sciences Services" (1.435) and "Neurosciences" (1.433) are among the health fields with the highest number of articles.

In the remainder of the study, a detailed analysis was conducted for the articles published from Türkiye in the field of AI in the field of healthtech. There is an accelerating increase in the number of articles published in the ten-year period between 2013-2022 (Figure 3a). When the AI articles published in the field of health are analyzed, it is observed that the WoS category-based distribution differs from the worldwide subject distribution (Figure 3b). Türkiye's focus on AI-based healthtech literature differs in terms of "Engineering Biomedical", which ranks first, and "Dentistry Oral Surgery", which ranks fourth.

Analyzing the Matrix Distribution of Publications Across Different Application Categories and Types of Publications

Based on the areas presented in Figure 2, the second part of the study analyzed technological and technical applications in the health sector and the quantitative and qualitative distribution of publications on these applications. While determining technological and technical applications, the approach is to classify the basic service titles that a person receives from the health system (diagnosis, drug, healthcare, surgery, therapy, treatment) and to reveal the research intensity for the development of existing technological opportunities in these titles with AI. Table 1 summarizes the results of the analysis. While research on the use of AI in "Diagnosis" and "Treatment" applications is at the forefront, the use of AI in "Surgery" and "Drug" applications has not yet gained weight in research and publications. A previous literature review on the role of AI in healthcare identified four major clusters in the field: Health services management, Predictive medicine, Clinical decision-making, and Patient data and Diagnostics (12).
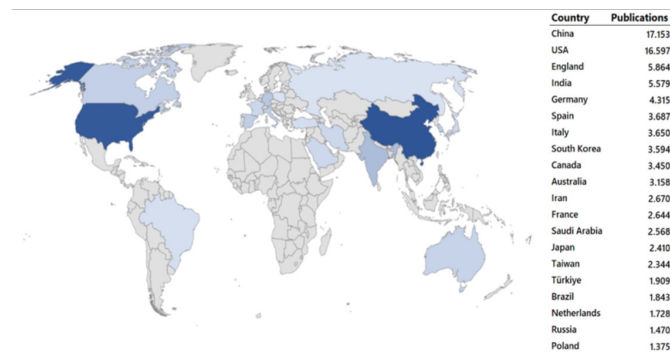

Figure 1: Geographical distribution of top 20 countries (Türkiye in 16th place) in publishing research articles about "artificial intelligence" topic. The tone of the blue is in correlation with the number of articles for each country
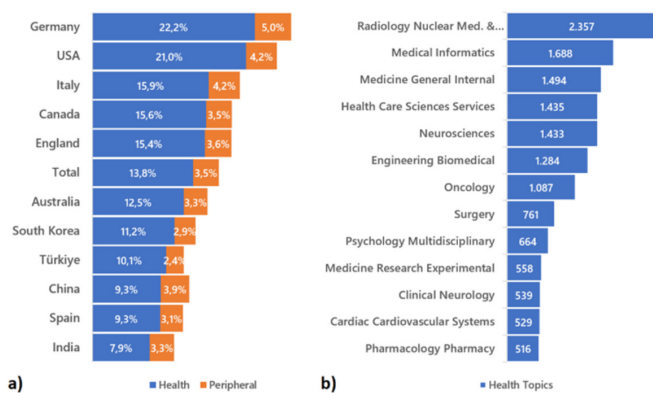
Figure 2: Distribution of countries and topics in the field of health. **a)** Distribution of health (blue bars) and other fields that may be related to health (orange bars) in the publications on AI published by the top 10 countries and Türkiye. **b)** Distribution of health fields with more than five hundred AI publications worldwide

AI: Artificial intelligence
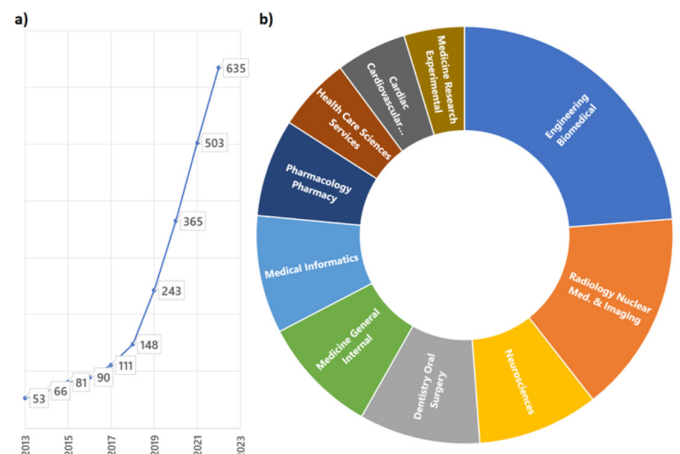
Figure 3: Publications on artificial intelligence from Türkiye. **a)** Graph of research articles by years. **b)** Distribution of publications in the field of health according to WoS categories

WoS: Web of Science

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| Table 1: Matrix distribution of publications with respect to applications and publication types						
	Article	Book	Chapter	Proceeding	Review	Total
AI	80.620	102	1.806	34.725	12.163	135.238
Diagnosis	8.486	3	90	1.945	3.119	13.868
Drug	1.598		34	170	1.034	2.924
Healthcare	2.970		67	728	1.232	5.164
Surgery	1.352	1	14	126	561	2.187
Therapy	1.675		37	199	3.009	2.967
Treatment	4.912		71	734	2.132	7.935
Total	**101.613**	**106**	**2.119**	**38.627**	**23.250**	**170.283**
AI: Artificial intelligence						

When examining the evolution of technological and technical healthcare applications and publication types over the years, the findings depicted in Figure 4 become apparent. Figure 4a illustrates a consistent annual increase in publications related to AI in the health sector, with research articles being the driving force behind this growth. Additionally, Figure 4b reveals a noticeable uptick in publications across all categories of technological and technical applications within the study's scope throughout the years. Overall, it has been observed that experts and academics have increasingly begun conducting research in the domains of health technologies and techniques, with a notable surge in interest over the past year, starting from 2018.

Citation topics classification of Clarivate gives us an opportunity to up-to-date location and relevance of published articles in the multi-dimensional space of scientific literature. Because not only the writers' choice about the topic of the study but also the topics of citing and cited articles are taken into account of this classification that gives any scientific study its more accurate research area. There are three different tier of Citation Topics classification of Clarivate (each having different number of classifications); macro (10), meso (326) and micro (2488). To streamline and enhance our understanding of the distribution of articles related to AI in healthcare, a meso classification approach was selected for citation topics. Readers interested in conducting an in-depth analysis of a specific topic are advised to utilize the micro classification of citation topics. In the ultimate examination of this subtopic, we analyzed meso classifications within Macro Citation Topic 1: Clinical & Life Sciences (9). From the research articles extracted from the WoS database, the top 10 Citation Topic Meso classifications were identified (displayed on the left side of the Sankey diagram in Figure 5). For each of these classifications, we analyzed the distribution of technological and technical application topics that were the primary focus of this study.
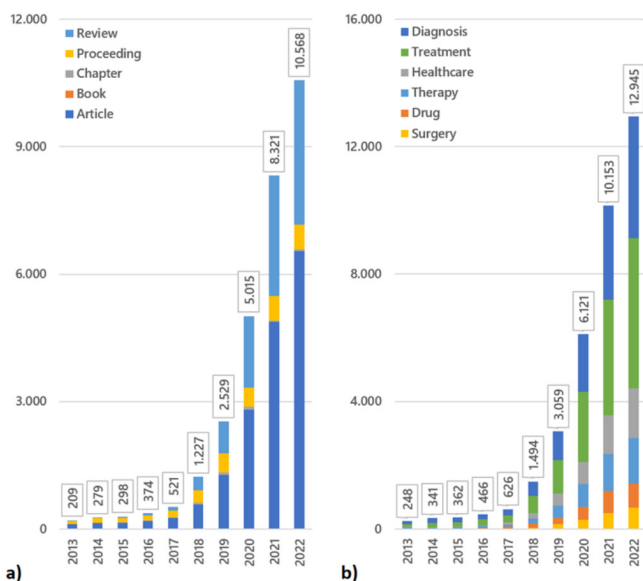
Figure 4: Temporal analysis of artificial intelligence research articles in health. **a)** publication type trend, **b)** Technological/technical application type trend
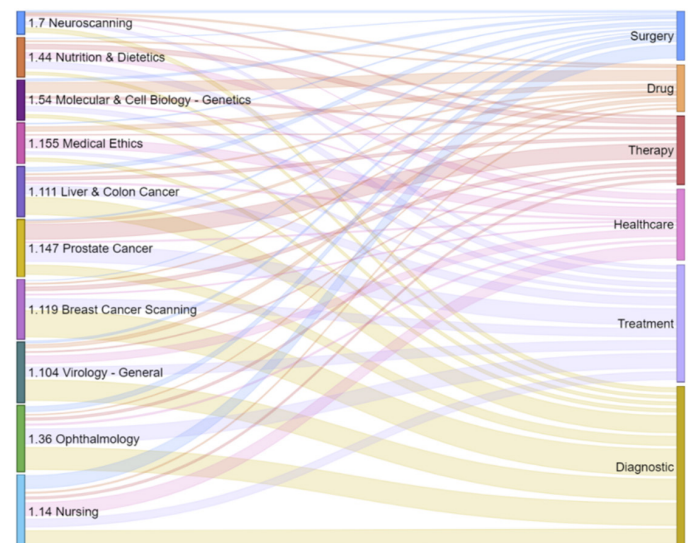

Figure 5: The Sankey diagram illustrates the connections and correlations between the top 10 Citation Topic Meso classifications and the technological and technical applications at the center of this study. The thickness of the connections represents the relative concentration of research articles. Numbers before the classifications represent the coding of Clarivate

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Assessing the Influence of AI Technology on Innovation and Public Perception

In the last part of the study, a sentiment analysis was analyzed in terms of the social perception of the AI knowledge produced by countries in different areas of the health sector and its counterpart in technological start-up companies and investors. For this purpose, the companies and investors in the dealroom.co database are analyzed according to healthtech topics. Dealroom.co is one of the most comprehensive databases of the start-up ecosystem, trusted by world-class companies worldwide. Thus, it was preferred for this study that can give an idea about the enterprises in the world. Seventy-seven firms were listed working in healthtech and AI whose countries of origin and technological expertise related with AI (Figure 6). There is no company from Türkiye among these 77 companies analyzed.

An interesting result emerged when these start-up companies were analyzed according to the year of establishment. It was found that the companies established three years before (2015) the increase in academic publications (2018) received international investments and experienced significant valuations. This finding reveals the potential of AI applications in healthcare. When the country breakdowns in Figure 1 and Figure 2 a are compared with the digital therapeutics and healthtech investors in the Dealroom.co database (13), the picture that emerges is that, although there are academic studies in different countries, innovation and the evaluation of the knowledge produced by technology firms are concentrated in the US, the UK and Israel. While the valuations of firms are constantly increasing, it was observed that this valuation created a temporary increase during the COVID-19 pandemic.
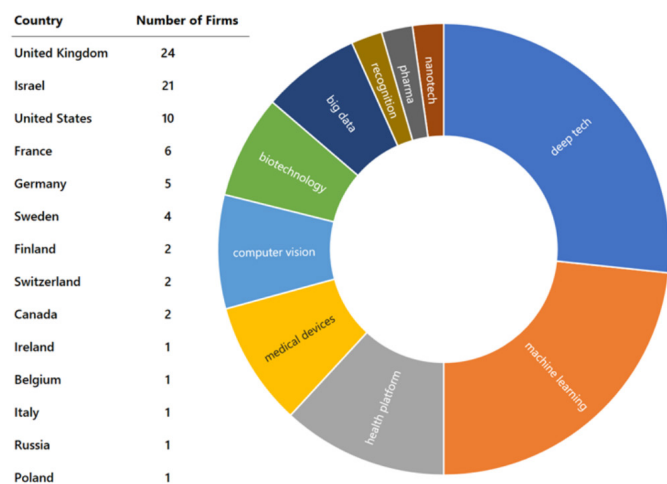

Figure 6: Distribution of AI technology start-up companies listed in dealroom.co, operating in the field of healthcare by country and expertise topics. Start-ups may have more than one expertise topic
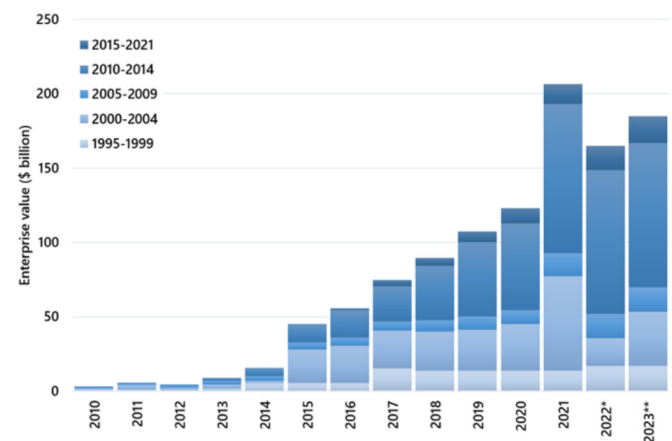
AI: Artificial intelligence

Furthermore, the reflection of the concept of AI in health on society from a scientific and technological perspective was analyzed before and after the COVID-19 pandemic through Google Trends. The Google Trends data in Figure 7, which shows the worldwide AI searches in the field of health, was subjected to forecasting analysis from January 2020 (the month when the pandemic was accepted as effective worldwide), and the predicted and actual social perception was analyzed. In contrast to the findings in Figure 8, there was a decline in Google searches related to health at the outset of the pandemic. Following the pandemic, there was a significant surge in social interest, as indicated by previous years' data.

Discussion

The primary emphasis of this study on country-based perspectives reveals the evident dominance of the USA and China in the realm of AI. The technological equivalent of the
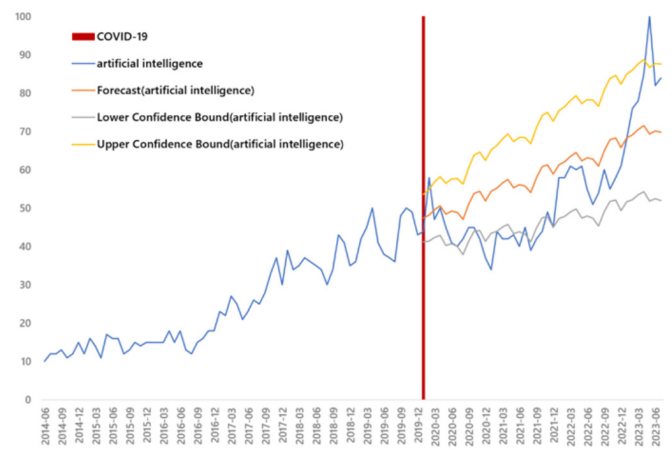
Figure 7: Forecasting for sentiment analysis of Google Trends data about "artificial intelligence" in health

COVID-19: Coronavirus disease-2019

Figure 8: Enterprise valuation of artificial intelligence start-ups in digital therapeutics and healthtech. Columns are stacked with respect to year of foundation

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ongoing race between the two countries across diverse domains has also been identified in the field of healthcare-related AI studies. As can be seen in Figure 2a, this competition in the field of AI technology does not continue in the field of healthtech, where the rate of articles on health is 21% in favor of the USA, while China's rate is relatively low at 9.3%. This is an indication that the US will emerge as a new technological field in which the US will gain superiority over China, which has caught up with the US in many fields. It should also be considered that a similar competitive process has historically taken place in the fields of biotechnology and nanotechnology, which marked health technologies before AI.

When the sub-headings in the field of health are examined; Rheumatology (53), Developmental Biology (30), Primary Health Care (23), Tropical Medicine (23) and Anatomy Morphology (16) were identified as the fields with the least number of articles on AI, although not shown in Figure 2. It has been determined that there are still opportunities for researchers in these fields. As can be seen in Figure 3, given that Türkiye publishes proportionally fewer publications in the field of "Medical Informatics", there is a risk of falling behind compared to the world in the fields of digital therapeutics and healthtech. On the other hand, in the field of pharmacology, there is a focus on publications proportionally above the world average. Especially as a result of the opportunities offered by biotechnology and nanotechnology, pharmaceutical technology, which has progressed positively in terms of efficacy and side effects, is likely to make a breakthrough again with AI (especially machine learning), which could be an advantage for Türkiye in terms of clinical application success - considering health tourism.

The quantitative and qualitative comparison of the publications in Table 1 presents an important finding. The problem encountered during the technological and technical application areas in retrieving data from the WoS database is that the words "diagnosis" and "treatment" have uses other than health. Although necessary eliminations were tried to be made during filtering, there is a risk that the figures may be higher than they are, since it is not possible to examine individual publications. This was overcome with the Citation Topics Meso approach in the rest of the study. However, the main result that emerges from Table 1 is that there are relatively few AI publications on "Drug". This suggests that there is still a potential gap in the use of AI in "healthtech" in academic studies. The relatively high number of AI papers on pharmacology coming out of Türkiye, discussed in the previous paragraph, once again emphasizes the potential for Türkiye-based studies and researchers. In addition, looking at the types of publications in the field of health, it has been determined that academic book production has not yet been realized because fixed and generally accepted knowledge has not yet been established.

The examination of the technological and technical application steps presented in Figure 4 on a yearly basis is a preliminary study. Following the graphical curves in terms of quantity and quality over the years will provide information on the direction and saturation status of technological research. When the articles on health are analyzed through Citation Topics determined by WoS, the areas where technology is concentrated are presented to the attention of the readers with this study. Understanding the consequences of Figure 5; it is important to note that, 3 of the top 10 classifications are related with cancer (1.119 Breast Cancer, 1.147 Prostate Cancer, 1.111 Liver & Colon Cancer), which can be expected since previous technological breakthroughs like biotech and nanotech have been intensely utilized for the same aim: fight against cancer. However other interesting finding is 3 of the top 10 classifications are amongst the peripheral topics mentioned in Figure 2 (1.104 Virology, 1.54 Molecular & Cell Biology - Genetics, 1.44 Nutrition & Dietetics). Virology is mostly due to COVID-19 pandemic according to the investigation in the articles (data not shown).

Upon analyzing the distribution of organizations established with the objective of employing AI technology in healthcare across different countries, it is evident that, in contrast to Figure 1, companies from the UK and Israel are leading the way. In addition, although AI is generally a "software" subject, 24 of the analyzed companies also work in "medical devices", 20 in "biotechnology" and 6 in "nanotechnology". This situation demonstrates the diverse applications of AI technologies across various disciplines for the end user.

Conclusion

In conclusion, the use of AI in healthcare appears to be on the rise, both in building scientific knowledge and in AI-powered healthcare applications. AI related health research and its application in the health sector has been steadily increasing between the years of 2013-2022. Apparently, the breaking point of this progress was the COVID-19 outbreak, which caused disruptions in health care around the world. The results also reveal the sub-topics in the field of health that have not drawn enough interest that may drive the attention of researchers. Although the establishment of start-ups focused on this technology is limited to certain countries, their progress is promising. It is clear that the employment of AI in healthcare will expand as companies overcome both financial and regulatory issues.

Ethics

Ethics Committee Approval: No need for ethics committee approval in this study.

Informed Consent: No information consent was obtained since no patient was included in the study.

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Authorship Contributions

Concept: M.K., Design: M.K., Data Collection and Processing: M.K., E.M., A.A., Analysis or Interpretation: E.M., A.A., Literature Search: E.M., A.A., Writing: M.K., E.M., A.A.

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