Original Research Article

Digital health research: A scientometric assessment of global publications output during 2007–2016

B. M. Gupta, S. M. Dhawan[1], K. K. Mueen Ahmed[2]

1173 Sector 15, Panchkula, Haryana, [1]114 Dayanand Vihar, Delhi, [2]Phcog.Net, Cox Town, Bengaluru, Karnataka, India

Abstract

Aim and Scope: To study the scientometric assessment of global publications on Digital Health Research. **Methods:** The paper examines digital health research covering 6981 global publications sourced from Scopus database during 2007–2016. **Results:** Digital health research across 109 countries registered 8.03% growth and averaged to 7.33 citations per paper. The top 10 most productive countries individually contributed 2.75% to 33.82% share to global publications output and together they accounted for 79.30% share during the period. Their international collaborative publications varied from 3% to 14.49%. Medicine is the most studied subject with largest publication share in digital health research (53.55%), followed by computer science (33.85%), engineering (24.97%), health profession (13.24%), and others. The top 20 most productive organizations and authors together contributed 12.32% and 2.99% of global publications share, respectively, and 38.91% and 3.28% of global citations share, respectively. The top 20 journals contributed 12.32% share to the global output in journals during 2007–2016. Of the total digital health research, 46 (0.65%) were highly cited papers, citations to them ranged from 100 to 1104 per paper, with 257.76 citations per paper. **Conclusion:** A total of 415 authors from 242 organizations contributed 46 highly cited papers which appeared in 37 journals. Four papers appeared in CA *Cancer Journal of Clinicians*, three papers in *Annals of Internal Medicine*, two papers each in *European Urology*, *Journal of American Medical Informatics Association*, *New England Journal of Medicine*, *Pediatrics* and *Stroke*, and one paper each in 30 other journals.

Keywords: Bibliometrics, digital health, digital healthcare, digital technologies, global publications, health, Scientometrics

Address for correspondence: Dr. K. K. Mueen Ahmed, Phcog.Net #17, II Floor, Buddha Vihar Road, Cox Town, Bengaluru - 560 005, Karnataka, India.
E-mail: mueen.ahmed@gmail.com

INTRODUCTION

Latest advances in wireless connectivity, sensors and the growth of mobile devices and such other digital technologies are allowing organizations to move to virtual healthcare model to regularly monitor patients' health from the remote. In addition, these technologies support monitoring certain other types of digital health activities, including health-care analytics and population health management. The factors driving increased interest in digital health are as follows: (a) clear requirement to curtail increasing healthcare costs, (b) the need to find new ways to handle the growing number of individuals with chronic diseases, and (c) the desire to provide better and safer medical care. The key players in the healthcare ecosystem are searching for better and better ways to support aging populations and improve patient satisfaction. While digital health is by no means a silver bullet, but if properly implemented and managed, it can certainly provide a new way for organizations to

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make progress on their goals.[1] The current digital health technologies do have the potential to revolutionize the existing healthcare delivery. Digital tools can increase access to health, empower patients and provide better information and education for all. They can also facilitate the use of real-time data to ensure that surveillance systems are more action oriented and prioritize limited resources.[2]

According to recent International Telecommunication Union (ITU) report and other scholars, digital health is as an umbrella term to encompass all concepts and activities at the intersection of health and information and communication technologies (ICTs), including mobile health (include wearable and software applications), health information technology, health analytics (software solutions and analytical capabilities to assimilate big data), digital health systems (digital health information storage and exchange of digitalized patient medical records-including both electronic health records and e-prescribing), and Telehealth (the use of telecommunication technologies such as video and imaging to support virtual delivery of health care services and health education) and personalized medicine (use of information about an individual's genetic profile and environment to prevent, diagnose, and treat disease). Digital health encompasses the following three functions: (i) the delivery of health information for professionals and health consumers through the internet and telecommunications medias; (ii) Using ICTs to improve public health services (e.g., through education and training of health workers); and (iii) Using health information systems to capture, store, image or transmit health information on patient or health facility activities.[1,3,4]

The digital health market is expected to grow by a compounded annual growth rate by 26% (CAGR) over the next several years. By 2024, the digital health market is estimated to top $379 billion, according to research from global market insights. Different components of digital health will grow at varying rates. Mobile health, for example, is expected to grow at a sizzling 34% CAGR through 2022. The global Telehealth market is projected to grow by a 30% CAGR during the period. The wearable device market could grow by close to a 16% CAGR by 2022. The personalized medicine market is expected to grow at a CAGR of nearly 12% during the period. Meanwhile, the hit market is projected to go up at a 7% CAGR.[3]

No study is available till date on quantitative and qualitative analysis of digital health research output. However, bibliometrics studies were carried out in the broader areas, such as mobile health, telehealth, and digital medicine. Among studies on mobile health research, Sweileh *et al*.[5] analyzed mobile health publications sourced from SciVerse Scopus database covering 2006–2016. The authors analyzed publications output growth and citation impact, geographical distribution, collaboration pattern, identification of top institutions, journals and cited articles, etc. Foozonkhah and Kalankesh[6] analyzed global trends in mobile health from January 1898 to December 2014, using downloaded from the WoS database. They studied publication growth, publications output and citations received, and top 10 productive countries, etc., Among studies on Telehealth, Yang *et al*.,[7] identified trends in telemedicine literature covering 1993–2012, using data sourced from SCI-Expanded database, describe future directions of research in this area. Fatehi and Wootton[8] studied 11644 documents containing one of the three terms, namely telemedicine, telehealth, or e-health using data sourced from the Scopus database. The authors determined the trends over the past few years and identified differences in the usage of three terms across different countries. Fang[9] analyzed and visualized the structure and the emerging trends of digital medicine consisting of 6060 documents. Cite space was used to visualize the perspective of digital medicine domain. This study seeks to ascertain the quantitative and qualitative performance of global digital health research during 2007–2016, based on publications sourced from the Scopus database. In particular, the study will focus to study the growth rate in global research output in digital health and its citation impact; contribution and citation impact of top 10 most productive countries; to study the international collaboration share of top 10 most productive countries; to study the global research output by broad subject areas and the dynamics of its growth and decline and also study the trends by identifying significant keywords; to study the publication productivity and citation impact of top 20 most productive organizations and authors; to study the modes of communication in research and identify the top 20 most productive journals; and to study the characteristics of top 46 highly cited papers registering 100 or more citations.

METHODOLOGY

Digital health research data of the world covering the 10-year period 2007–2016 was sourced from the Scopus database (http://www.scopus.com) covering the period 2007–2016. In formulating the main search strategy, keywords such as "digital health" or "m-health" or "mobile health" or "e-health" or "electronic health" were searched using search tags such as "keyword," "article title," and "source title." In addition, date range tag was limited to the period "2007–2016". The global publication data on digital health research retrieved 6981 records.

This main search strategy was later refined by country name tag to get digital health output of the top 10 most productive countries. By using analytical functions available in the Scopus database, publications data was further refined to get data distributed by subject, collaborating countries, author-wise, organization-wise, journal-wise, etc. For citation data, citations to publications were collected from the date of publication to May 13, 2017. A series of raw and relative bibliometric indicators were used to understand the dynamics of digital health research. A complete counting method was used, wherein every contributing author or organization covered in multiple authorship papers was fully counted. All authors or organizations to multi-authored papers were given equal credit in data counting and analysis.

(key ["digital health" or "m-health" or "mobile health" or "e-health" or "electronic health"] or title ["digital health" or "m-health" or "mobile health" or "e-health" or "electronic health"] or source title ["digital health" or "m-health" or "mobile health" or "e-health" or "electronic health"]) and pubyear >2006 and pubyear <2017.

RESULTS AND DISCUSSION

The digital health research in the world, as seen from Scopus database, cumulated to a total of 6981 publications in 10 years during 2007–2016, registered 8.03% annual growth, up from 536 in 2007–878 publications in 2016. However, its absolute growth in 5-year was 33.84%, up from 2990 in 2007–11–3991 publications in 2012–2016. Of the total global publications output in digital health, 44.06% (3076) appeared as articles, 38.91% (2716) as conference papers, 8.04% (561) as reviews, 2.12% (148) as editorials, 1.70% (119) as letters, 1.60% (112) as notes, 1.55% (108) as book chapters and the rest as short surveys, (77) articles in press (40), conference reviews (13), books (7), and erratum (4). Of the global publications output, 96.58% (6742) appeared in English, followed by 1.02% (71) in German, 0.74% (52) in Chinese, 0.66% (46) in Spanish, 0.46% (32) in Portuguese, and the rest in other languages.

The citation impact of digital health research averaged to 7.73 Canada pension plan (CPP) during the period; its 5-year impact declined from 11.33 CPP for 2007–11–5.04 CPP for output in the succeeding 5-year period 2012–2016 [Table 1].

Table 1: World Publications and Citations Output in Digital Health Research, 2007-2016

Publication period	World		
	TP	TC	CPP
2007	536	6530	12.18
2008	612	8236	13.46
2009	520	7598	14.61
2010	755	4888	6.47
2011	567	6616	11.67
2012	639	6028	9.43
2013	706	5011	7.10
2014	735	3828	5.21
2015	1033	4387	4.25
2016	878	849	0.97
2007-11	2990	33,868	11.33
2012-16	3991	20,103	5.04
2007-16	6981	53,971	7.73

TP: Total papers, TC: Total citations, CPP: Citations per paper

Top 10 most productive countries in digital health research

The digital health research had originated from as many as 109 countries in the world during 2007–2016. Top 10 most productive countries in digital health research are as follows: USA (33.82% highest global publications share), followed by China and U. K. (9.83% and 9.01%), Germany, Canada, and Australia (6.67%, 4.60%, and 4.41%), Italy and India (3.75% and 3.62%) and France and Spain (2.84% and 2.75%) during 2007–2017. Their individual global publications share ranged between 2.75% and 33.82% and together they contributed 79.30% of global publications share during the 10-year period. The research activity across these countries was dynamic. In most countries (USA, UK, India, Canada, Germany, Australia, Spain, Italy, and France), their 5-year global publications share increased by 0.17% to 3.46%. In China, it dropped by 8.21% during the period between 2007–2011 and 2012–2016. The relative citation index in 9 out of top 10 countries was above the world average 1.26: France (1.88), Italy (1.73), USA (1.53), Canada (1.41), and Spain (1.31) during 2007–2016 [Table 2].

International collaboration

In digital health research, the international collaborative share of top 10 countries national outputs varied from 3.10% to 14.49%, with France (14.49%) accounting for the highest share, followed by Italy (13.35%), USA (11.85%), Canada (10.93%), U. K. (10.13%), Spain (9.66%), Australia (8.32%), Germany (7.66%), China (3.20%), and India (3.10%) during 2007–2016.

Subject-wise distribution of research output

The digital health research is distributed across six sub-fields (as identified in Scopus database classification), with medicine accounting for the highest global publications share (53.55%), followed by computer science (33.85%), engineering (24.97%), health profession (13.24%), social sciences (6.93%), and biochemistry, genetics and molecular biology (6%) during 2007–2016. The research activity across these sub-fields was dynamic over time. In sub-fields such as social sciences, and biochemistry, genetics and

molecular biology, their activity index changed from below hundred to above hundred significantly. In other sub-fields, it changed from above 100 to below 100 across 5-year periods 2007–2011 to 2012–2016. The world average activity index of a given subject is taken as 100. Biochemistry, genetics, and molecular biology registered the highest impact 12.81 citations impact per paper followed by medicine (10.31), social sciences (6.27), engineering (4.68), health profession (4.38), and computer science (4.0) during the period [Table 3].

Profile of top 20 most Productive Global Organizations

Top 20 most productive organizations in global digital research contributed 29–77 publications each, and together they contributed 12.32% (860) global publications share and 38.91% (21001) global citations share during 2007–2016. Their scientometric profile is presented in Table 4.

- Eight of these organizations registered their publications productivity above the group average of 43.0: Harvard Medical School, USA (77 papers), Veterans Affairs Medical Center, Pittsburg, USA (71papers), University College London, U. K. (57 papers), Massachusetts General Hospital, USA and University of Washington, Seattle, USA (51 papers each), University of Toronto, Canada (46 papers), University of California, San Francisco, USA (45 papers), and University of Sydney, Australia (44 papers) during 2007–2016
- Seven organizations registered impact above the group average of 24.42 citations per publication during 2007–2016: University of California, San Francisco, USA (53.07), John Hopkins University, USA (47.48), Erasmus University Medical Center, Netherlands (45.32), Veterans Affairs Medical Center, Pittsburg, USA (41.69), National Cancer Institute, MD, USA (39.55), Massachusetts General Hospital, USA (38.06), and Harvard Medical School, USA (24.69) during the period
- Seven organizations registered h-index above the group average of 13.0: Harvard Medical School, USA (22), Veterans Affairs Medical Center, Pittsburg, USA (17), Massachusetts General Hospital, USA, University of Washington, Seattle, USA and Brigham and Women's Hospital, USA (16 each), University of California, San Francisco, USA and National Cancer Institute, MD, USA (14 each) during the period
- Ten organizations contributed international collaborative publications share above the group average of 29.07%: Erasmus University Medical Center, Netherlands (56.76%), University of Oxford, U. K.(40.0%), University College London, U.

Table 2: Global Publication, Citations and International Collaborative Papers Share of Top 10 Most Productive Countries in Digital Health Research during 2007-2016

Name of the country	Number of papers			Share of papers			TC	CPP	ICP	PeICP	RCI
	2007-2011	2012-2016	2007-2016	2007-2011	2012-2016	2007-2016					
USA	952	1409	2361	31.84	35.30	33.82	27976	11.85	409	17.32	1.53
China	434	252	686	14.52	6.31	9.83	2194	3.20	120	17.49	0.41
U.K.	219	410	629	7.32	10.27	9.01	6373	10.13	233	37.04	1.31
Germany	115	211	326	3.85	5.29	4.67	2498	7.66	116	35.58	0.99
Canada	112	209	321	3.75	5.24	4.60	3509	10.93	136	42.37	1.41
Australia	112	196	308	3.75	4.91	4.41	2562	8.32	100	32.47	1.08
Italy	105	157	262	3.51	3.93	3.75	3499	13.35	99	37.79	1.73
India	77	176	253	2.58	4.41	3.62	785	3.10	51	20.16	0.40
France	82	116	198	2.74	2.91	2.84	2870	14.49	98	49.49	1.88
Spain	70	122	192	2.34	3.06	2.75	1855	9.66	65	33.85	1.25
Total	2278	3258	5536	76.19	81.63	79.30	54121	9.78	1427	25.78	1.26
World	2990	3991	6981	100.0	100.0	100.0	53971	7.73			
Share of 10 countries in world total	76.19	81.63	79.30								

Table 3: Subject-wise breakup of Global Publications in Digital Health Research during 2007-2016

Subject*	Number of papers (TP)			Activity index		TC	CPP	Percentage TP
	2007-2011	2012-16	2007-2016	2007-2011	2012-2016	2007-2016	2007-2016	2007-2016
Medicine	1648	2090	3738	102.94	97.80	38,550	10.31	53.55
Computer science	1057	1306	2363	104.44	96.68	9441	4.00	33.85
Engineering	749	994	1743	100.33	99.75	8158	4.68	24.97
Health profession	585	339	924	147.82	64.17	4051	4.38	13.24
Social sciences	184	300	484	88.76	108.42	3037	6.27	6.93
Biochemistry, genetics and molecular biology	166	253	419	92.50	105.62	5366	12.81	6.00
World output	2990	3991	6981	100.00	100.00			

There is overlapping of literature covered under various subjects

TP: Total papers, TC: Total citations, CPP: Citations per paper

Table 4: Scientometric Profile of Top 20 Most Productive Global Organizations in Digital Health Research during 2007-2016

Name of the organization	TP	TC	CPP	HI	ICP	Percentage ICP	RCI
Harvard Medical School, USA	77	1901	24.69	22	29	37.66	3.19
Veterans Affairs Medical Center, Pittsburg, USA	71	2960	41.69	17	13	18.31	5.39
University College London, U.K.	57	505	8.86	10	22	38.60	1.15
Massachusetts General Hospital, USA	51	1941	38.06	16	9	17.65	4.92
University of Washington, Seattle, USA	51	1147	22.49	16	15	29.41	2.91
University of Toronto, Canada	46	649	14.11	13	16	34.78	1.83
University of California, San Francisco, USA	45	2388	53.07	14	11	24.44	6.87
University of Sydney, Australia	44	695	15.80	13	16	36.36	2.04
Brigham and Women's Hospital, USA	40	877	21.93	16	12	30.00	2.84
University of Pennsylvania, USA	38	749	19.71	12	13	34.21	2.55
Mayo Clinic, USA	37	673	18.19	11	9	24.32	2.35
University of Michigan, USA	37	429	11.59	12	7	18.92	1.50
University of California, Los Angles, USA	37	754	20.38	12	8	21.62	2.64
Erasmus University Medical Center, Netherlands	37	1677	45.32	13	21	56.76	5.86
University of Melbourne, Australia	35	243	6.94	10	8	22.86	0.90
University of Oxford, U.K.	35	321	9.17	10	14	40.00	1.19
National Cancer Institute, MD, USA	31	1226	39.55	14	8	25.81	5.12
Virginia Polytechnic Institute and State University, USA	31	201	6.48	8	5	16.13	0.84
University of Southern California, USA	31	288	9.29	9	5	16.13	1.20
John Hopkins University, USA	29	1377	47.48	12	9	31.03	6.14
Total of 20 organizations	860	21,001	24.42	13	250	29.07	3.16
Total of World	6981	53,971	7.73				
Share of top 20 organizations in World total output	12.32	38.91					

TP: Total papers, TC: Total citations, CPP: Citations per paper, HI: h-index, ICP: International Collaborative papers, RCI: Relative citation index

K.(38.60%), Harvard Medical School, USA (37.66%), University of Sydney, Australia (36.36%), University of Toronto, Canada (34.78%), University of Pennsylvania, USA (34.21%), John Hopkins University, USA (31.03%), Brigham and Women's Hospital, USA (30.0%), and University of Washington, Seattle, USA (29.41%) during the period

- Seven organizations registered their relative citation index above the group average (3.16) of all organizations: University of California, San Francisco, USA (6.87), John Hopkins University, USA (6.14), Erasmus University Medical Center, Netherlands (5.86), Veterans Affairs Medical Center, Pittsburg, USA (5.39), National Cancer Institute, MD, USA (5.12), Massachusetts General Hospital, USA (4.92), and Harvard Medical School, USA (3.19) during the period.

4.5 profile of top 20 most productive authors

Top 20 most productive authors in global digital health research contributed 8–21 publications each, and together they contributed 2.99% (209) global publications share and 3.28% (1771) global citations share during 2007–2016. Their scientometric profile is presented in Table 5.

- Six authors registered their publications productivity above the group average of 10.45: C. Niezrecki (21 papers), P. Avitabile (15 papers), P. Lall and D. Lupton (14 papers each), P. Gupta (12 papers), and P. Kostkova (11 papers) during the period
- Eight authors registered impact above the group average of 8.47 citations per publication: C. H. Bangma (26.88), S. Loeb (23.63), A. N. A. Tosteson (19.89), D. Lupton (16.86), K. Chakrabarty Duke University, USA (15.33), C. Costs (11.50), D. J. Inman (10.0), and D. S. Ha (8.78) during the period
- Eleven authors registered h-index above the group average of 4.35 of all authors: D. Lupton and C. Niezrecki (7 each), C. H. Bangma and P. Avitabile (6 each), S. Loeb, A. N. A. Tosteson, K. Chakrabarty, C. Costs, D. J. Inman, D. S. Ha and I. Bartoli (5 each) during 2007–2016
- Seven authors contributed international collaborative publications share above the group average of 12.0% of all authors: K. Chakrabarty (55.60%, A. N. A. Tosteson (44.40%, C. H. Bangma (37.5%), H. Underwood (37.5%), P. Kostkova (27.3%), S. Loeb (25.0%), and D. Lupton (21.4%) during the period
- Eight authors registered their relative citation index above the group average (1.10) of all authors: C. H. Bangma (3.48), S. Loeb (3.06), A. N. A. Tosteson (2.57), D. Lupton (2.18), K. Chakrabarty (1.98), C. Costs (1.49), D. J. Inman (1.29), and D. S. Ha (1.14) during the period.

Medium of research communication

Of the total world output in digital health research, 59.43% (4149) appeared in journals. The top 20 most productive journals accounted for 15–60 papers each and together accounted for 12.32% (511 papers) of total publication output appearing in journals during 2007–2016. Their publication share (top 20 most productive journals) decreased from 13.02% to 11.85% between 2007–2011 and 2012–2016. The topmost productive journal (with 60 papers) was *Journal of Digital Imaging*, followed by *International*

Journal of Medical Informatics and Journal of Medical Internet Research (39 papers each), *Journal of American College of Radiology* (38 papers), *American Journal of Roentgenology and Telemedicine and E-Health* (30 papers each), etc., during 2007–2016 [Table 6].

Significant keywords

Around 46 significant keywords have been identified from the literature, which point to possible trends in digital health research. These keywords are listed in Table 7 in the decreasing order of the frequency of occurrence during 2007–2016.

Highly cited papers

Of the total output in digital health research (6981), just 46 papers (0.65%) received 100–1104 citations per paper since their publication during 2007–2016. These 46 highly cited papers together received 11,857 citations, which averaged to 257.76 citations per paper.

Table 5: Scientometric profile of top 20 Most Productive Authors in Digital Health Research during 2007-2016

Name of the Author	Affiliation of the Author	TP	TC	CPP	HI	ICP	Percentage ICP	RCI
C. Niezrecki	University of Massachusetts, USA	21	88	4.19	7	0	0.0	0.54
P. Avitabile	University of Massachusetts, USA	15	72	4.80	6	0	0.0	0.62
P. Lall	Auburn University, USA	14	41	2.93	3	0	0.0	0.38
D. Lupton	University of Canberra, Australia	14	236	16.86	7	3	21.4	2.18
P. Gupta	Auburn University, USA	12	36	3.00	3	0	0.0	0.39
P. Kostkova	University College London, U.K.	11	22	2.00	3	3	27.3	0.26
I. Bartoli	Drexel University, USA	10	83	8.30	5	0	0.0	1.07
D.J. Inman	Virginia Tech, USA	10	100	10.00	5	1	10.0	1.29
A. Kontsos	Drexel University, USA	10	72	7.20	4	0	0.0	0.93
K. Chakrabarty	Duke University, USA	9	138	15.33	5	5	55.6	1.98
D.S. Ha	Virginia Tech, USA	9	79	8.78	5	1	11.1	1.14
A.N.A. Tosteson	Dartmouth Medical School, USA	9	179	19.89	5	4	44.4	2.57
P.A. Vanniamparambil	Drexel University, USA	9	68	7.56	4	0	0.0	0.98
C.H. Bangma	Erasmus MC University Medical Centre, Rotterdam, Netherland	8	215	26.88	6	3	37.5	3.48
J. Baqersad	University of Massachusetts, USA	8	32	4.00	3	0	0.0	0.52
Y. Cao	Henan Institute of Science and Technology, China	8	3	0.38	1	0	0.0	0.05
C. Costs	DETI/IEETA, University of Aveiro, Portugal	8	92	11.50	5	0	0.0	1.49
S. Loeb	John Hopkins University, USA	8	189	23.63	5	2	25.0	3.06
J. Ranck	RanConsulting, USA	8	1	0.13	1	0	0.0	0.02
H. Underwood	University of Colorado, USA	8	25	3.13	4	3	37.5	0.40
	Total of 20 authors	209	1771	8.47	4.35	25	12.0	1.10
	Total of World	6981	53971	7.73				
	Share of top 20 authors in World total output	2.99	3.28					

TP: Total papers, TC: Total citations, CPP: Citations per paper, HI: h-index, ICP: International collaborative papers, RCI: Relative citation index

Table 6: Top 20 Most Productive Journals in Digital Health Research during 2007-2016

Name of the Journal	Number of papers		
	2007-11	2012-16	2007-16
Journal of digital imaging	32	28	60
International Journal of Medical Informatics	22	17	39
Journal of Medical Internet Research	5	34	39
Journal of American College of Radiology	19	19	38
American Journal of Roentgenology	11	19	30
Telemedicine and E-Health	21	9	30
Journal of Medical Systems	8	19	27
PLOS one	4	23	27
Journal of Biomedical Informatics	5	18	23
Radiology	14	9	23
Academic Radiology	10	11	21
Applied Radiology	6	13	19
Journal of Urology	8	11	19
Stroke	6	13	19
Journal of American Medical Association (JAMA)	4	14	18
Journal of Medical Library Association	15	3	18
IEEE Transactions in Information Technology in Biomedicine	10	6	16
Journal of Neurointerventional Surgery	1	14	15
Journal of American Medical Informatics Association	6	9	15
Urology	7	8	15
Total of 20 journals	214	297	511
Total global journal output	1643	2506	4149
Share of top 20 journals in global journal output	13.02	11.85	12.32

Table 7: Significant keywords in literature on digital health research during 2007-2016

Keyword	Frequency	Serial number	Keyword	Frequency	Serial number	Keyword	Frequency
Health care	1154	17	NMR imaging	258	33	Digital Devises	172
Health	1131	18	Mammography	255	34	Digital Imaging communication in Medicine	154
Digital Storage	947	19	Signal Processing	251	35	Mobile Phones	153
Internet		20	Information Management	248	36	X-ray Topography	148
Digital Rectal Examination	517	21	Information Processing	247	37	Medical Information Systems	146
Structural health monitoring	409	22	Diagnostic Imaging	239	38	Cloud Computing	139
Digital Imaging	405	23	Breast Cancer	229	39	Digital Image Storage	134
Cancer Screening	347	24	Medical Imaging	218	39	Human computer communication	132
Prostate Cancer	333	25	Information Systems	215	40	Health Monitoring	131
Personal Digital Assistant	323	26	Digital Mammography	210	41	Medical Records	129
Telemedicine	321	27	Sensors	195	42	Digital Radiography	121
Image Processing	299	28	Medical Information	193	43	Information Retrieval	120
Digital subtraction angiography	295	29	Medical Informatics	187	44	Wireless Telecommunication Systems	117
Image Analysis	280	30	Electronic Health Records	181	45	Artificial Intelligence	116
Computer assisted topography	273	31	Medical Computing	181	46	Mobile Devises	113
Electronic medical records	266	32	Radiography	181			

- Of the 46 highly cited papers, 10 resulted from organizations in non-collaborative mode and 36 from two or more organizations (24 nationally collaborative and 12 international collaborative)
- Among international collaborative papers, the participation was largest from USA (43 papers), followed by Italy (7 papers), Netherlands (6 papers), Australia (6 papers), Netherlands and France (3 papers each), Canada, Spain and Saudi Arabia (2 papers each), Belgium, Germany, Poland, Norway, Switzerland, China, South Korea, Saudi Arabia, Brazil, Sweden, and New Zealand (1 paper each)
- These 46 highly cited papers were contributed by 415 authors from 242 organizations. The leading organizations were: Harvard Medical School, USA and University of California, San Francisco, USA (4 papers each), Massachusetts General Hospital, USA (3 papers), Veterans Affairs Medical Centre, Pittsburg, USA, University of Washington, Seattle, USA, University of Sydney, Australia, Brigham and Women's Hospital, USA, University of California, Los Angles, USA, Erasmus University Medical Centre, Netherlands (2 papers each), etc
- Of the 46 highly cited papers, 27 appeared as articles, 15 as review papers, 2 as short surveys, and 1 as conference paper
- These 46 highly cited papers were published in 37 journals; 4 of which appeared in in *CA Cancer Journal of Clinicians*, 3 in *Annals of Internal Medicine*, 2 papers each in *European Urology, Journal of American Medical Informatics Association, New England Journal of Medicine, Pediatrics* and Stroke, and 1 paper each in 30 other journals, namely *Addiction, Applied Microbiology and Biotechnology, Archives of Internal Medicine, Cancer, Cancer Epidemic Biomarkers and Prevention, Circulation, Environment Science and Technology, Health Affairs, Health Information and Library Journal, IEEE Journal on Selected Areas of Communication, IEEE Transactions on Neural Systems and Rehabilitations, International Journal of Distributed Sensor Network, Landscape Ecology, Journal of Biomedical Informatics, Journal of Infrastructural Systems, Journal of National Cancer Institute, Journal of Rheumatology, Journal of Sexual Medicine, Journal of Urology, Landscape Ecology, Medical Care Research and Revien, Modern Pathology, Nature Clinical Practice Oncology, Neurocritical Care, New Biotechnology., Physics in Medicine and Biology, PLOS One, Proceedings of the USA National Academy of Sciences, Sensors and Actuators. B* and *The Lancet*.

CONCLUSION

The present study is a quantitative and qualitative description of digital health research (6981 publications) in the world in 10 years (2007–2016), as indexed in the Scopus database. The digital health research conducted across 109 countries registered 8.03% growth, contributed

6981 publications, and averaged citation impact of 7.73 citations per paper during the period. Top 10 countries in digital health research (accounting for the bulk of 79.30% global publications share) are as follows: USA (33.82% global publications share), followed by China, U. K., Germany, Canada, Australia, Italy, India, France, and Spain (range 2.75% to 33.82%) during the period. Five of top 10 countries registered relative citation index above the world average are France, Italy, USA, Canada and Spain during the period. Top 10 countries differ in their share of international collaborative publications between 3.10% and 14.49% of their national output.

Medicine was the largest research subject (53.55%) followed in digital health research, followed by computer science (33.85%), engineering (24.97%), health profession (13.24%), social sciences (6.93%) and biochemistry, genetics, and molecular biology (6.0%) during 2007–2016. The top 20 most productive organizations in digital health research are:--Harvard Medical School, USA (77 papers), Veterans Affairs Medical Centre, Pittsburgh, USA (71 papers), University College London, U. K.(57 papers), Massachusetts General Hospital, USA, University of Washington, Seattle, USA (51 papers each), University of Toronto, Canada (46 papers), University of California, San Francisco, USA (45 papers) and University of Sydney, Australia (44 papers), etc. The top highly cited organizations are:---University of California, San Francisco, USA (53.07 citations per paper), John Hopkins University, USA (47.48), Erasmus University Medical Centre, Netherlands (45.32), Veterans Affairs Medical Centre, Pittsburgh, USA (41.69), National Cancer Institute, USA (39.55), Massachusetts General Hospital, USA (38.06) and Harvard Medical School, USA (24.69), etc., during the period.

The top 20 most productive journals with a focus on digital health research accounted for 12.32% share of total publications in journals medium during 2007–2016. The most productive journals include *Journal of Digital Imaging* (60 papers), *International Journal of Medical Informatics* and *Journal of Medical Internet Research* (39 papers each), *Journal of American College of Radiology* (38 papers), *American Journal of Roentgenology and Telemedicine and E-Health* (30 papers each), etc., during 2007–2016.

Just 46 publications in digital health research (0.65%) registered high citations, in the range of 100–1104 citations per paper, and averaged 257.76 citations per paper. The bulk of the highly cited papers resulted in two or more organizations (24 nationally collaborative and 12 international collaborative). Of the 46 highly cited papers, 43 were from USA, followed by Italy (7 papers), Netherlands (6 papers), Australia (6 papers), Netherlands and France (3 papers each), Canada, Spain and Saudi Arabia (2 papers each), Belgium, Germany, Poland, Norway, Switzerland, China, South Korea, Saudi Arabia, Brazil, Sweden and New Zealand (1 paper each). 415 authors from 242 organizations contributed to 46 highly cited papers.

Digital health research is still in its nascent stage. The study concludes that nations can catalyze their quantitative and qualitative research capacities more speedily through research collaborations at national and international levels. The digital healthcare sector is poised for a big boom in the coming decade. However, despite the long-term gains in efficiencies and costs that can be achieved, imbibing digital healthcare systems in hospitals poses big challenges such as the initial high capital investments in advanced technologies, lack of in-house IT expertise, lack of standards, reluctance/resistance of staff, and inadequate support from the IT vendors, etc., All national governments, therefore, need to formulate a national digital health strategy in line with suggestions proffered by the WHO-ITU National Health Strategy Toolkit. The three potential governance mechanisms that can guide the implementation of national health strategy are: (i) Sustained senior government leadership and committing financing for digital health are prerequisites for a successful national digital health strategy; (ii) Effective governance mechanisms that engage stakeholders, who have clearly defined roles, can help to ensure efficient decision making for a national digital health strategy and (iii) A national ICT framework that facilitates alignment between health and ICT sectors can promote connectivity and interoperability, establish common standards and enable appropriate policies and regulations in digital health.

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Conflicts of interest

There are no conflicts of interest.

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