Health Policy and Technology 8 (2019) 179–191

Contents lists available at ScienceDirect

Health Policy and Technology

journal homepage: www.elsevier.com/locate/hlpt

Literature Review

Worldwide implementation of telemedicine programs in association with research performance and health policy

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ARTICLE INFO

Article history:
Available online 18 April 2019

Keywords:
Telemedicine
Information and communication technologies
Health care policy
Legislation
Research performance
International collaboration

ABSTRACT

Objectives: We analyzed research performance, international collaboration, corporate contribution, country level economic factors, and legislative frameworks in association with worldwide implementation of telemedicine programs.
Methods: We identified telemedicine scholarly output in EMBASE and SCOPUS and SciVal and combine with Third Global Survey on eHealth available in the World Health Organization Global Observatory for eHealth.
Results: From 71245 telemedicine-related publications only 0.8% addressed a policy of tele-healthcare delivery. Scholarly output was positively associated with implementation of telemedicine, with legal framework supporting utilization of telemedicine and with country income and total health expenditure but not total population, physician, nurses or hospital bed density or life expectance. National eHealth policy, capacity building (training of medical students and staff), legislative regulations of electronic health records, and supply chain management information systems supported by information and communication technologies were associated with implementation of all examined telemedicine programs. 43 telecommunication technology or medical devices manufacturing companies contributed to more than 90% of scholarly output and implementation of telemedicine.
Conclusions: Research performance, training of medical students and healthcare professionals and collaboration with technology industry demonstrated the strongest association with implementation of telemedicine. Future efforts should be directed toward consistent collection and routine analysis of patient outcomes after telemedicine interventions. International legislation is needed for telemedicine capacity building, reimbursement policy, and secure data sharing policies.

Introduction

Telemedicine interventions show promise in improving patient outcomes and access to cost-effective healthcare in various populations and settings [1-21]. Country-specific legal and policy barriers, inadequate healthcare funding, organization, medical staff related barriers and poor patient access to mobile devices preclude extensive implementation of telemedicine worldwide [22-26]. The Organization for Economic Cooperation and Development Working Group found large cross-national variations in availability and use of telecommunications technologies to support health care delivery [27]. The World Health Organization (WHO) Global Observatory for eHealth reported positive worldwide trends in the implementation of eHealth policies and programs including telehealth [28,29]. However, only 22% of countries reported having an explicit national telemedicine policy or strategy [28,29]. Adoption of various telemedicine programs including teleradiology (in 77% of countries), teledermatology (in 46% of countries), telepsychiatry (in 34% of countries), telepathology (in 52% of countries), and patient remote monitoring (in 47% of countries) varied among countries and regions [28]. The association between the implementation of telemedicine programs with specific legal frameworks and country population, healthcare density, and patient access to Internet and communication technology remains unclear [28]. World-wide databases, including the Organization for Economic Co-operation and Development, do not collect data regarding implementation of telemedicine programs [30]. The association between academic and industry research performance and research impact with country implementation of telemedicine programs has not yet been evaluated.

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https://doi.org/10.1016/j.hlpt.2019.04.001
2211-8837/

Assessment of specific national policies and research performance in countries with versus without implementation of telemedicine programs can be useful for effective evidence-based decisions ensuring universal access to the best possible healthcare for populations in need [28,29].

We aimed to conduct empirical exploratory analysis of the legal, economic, and research-related factors associated with the implementation of telemedicine programs in various countries.

Methods

Study design

We conducted an empirical country-level analysis of the worldwide implementation of telemedicine programs using accepted policy evaluation methodology [31-34]. Since randomized experimental design is not feasible in policy analyses, we conducted an observational assessment of legal, economic, and research-related factors associated with the implementation of telemedicine programs around the world [34-37]. Our objectives included analyses of the research performance, international collaboration, corporate contribution, country level economic factors, and legislative frameworks in association with the implementation of telemedicine.

Definitions of telemedicine

We used definitions of telemedicine provided by publication services and governing organizations. For instance, we used a definition of telemedicine provided by the National Library of Medicine: “Delivery of health services via remote telecommunications. This includes interactive consultative and diagnostic services” [38]. The Centers for Medicare & Medicaid Services provided a similar definition of telemedicine as “professional services given to a patient through an interactive telecommunications system by a practitioner at a distant site” [39]. We also used a definition provided by the WHO: “The delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities” [40].

Data sources to evaluate country-level economic factors, policies, and implementation of telemedicine: We analyzed the data from the WHO Global Observatory for eHealth to examine the association between telemedicine publication activity and impact with country level national policies, strategies, funding, legal framework for electronic healthcare, legislation governing the use of the national electronic health record system and the use of big data in the health sector, and national telehealth program implementation [29,40]. We analyzed countries’ investment in research and development using the data from the Organization for Economic Co-operation and Development (https://data.oecd.org). We identified country specific policy and legislative documents in Google Scholar, LexisNexis legal database, and websites of the relevant associations, including the National Telehealth Policy Resource Center (https://www.cchpca.org/about/projects/national-telehealth-policy-resource-center), the American Telemedicine Association (ATA, http://www.americantelemed.org/home), the German Society of Telemedicine (https://www.dgtelemed.de/index.php?lang=en), and the French Society for Telemedicine (https://www.isfteh.org/) [41–43].

Data sources to evaluate research activity at country level: We searched EMBASE and Scopus databases in September 2018 to identify publications on telemedicine, telehealth care delivery, and related policy. As key words, we used telemedicine, telehealthcare delivery, policy, telecardiology, teleconsultation, teledermatology, telediagnosis, telemonitoring, telepathology, telepsychiatry, teleradiology, teleradiotherapy, telerehabilitation, and teletherapy.

We analyzed the retrieved results by year of the publication, country, authors’ names, affiliation, academic and international collaboration, and device manufactures.

Data sources to evaluate research performance: We analyzed research performance data since 2013 for publication sources, authors, and technology manufactures using the SciVal database [44].

Statistical analyses

We examined a correlation between country population, spending on research and development, research performance, and publication activity related to telemedicine. We tested hypotheses of the association between spending on research and development, scientific productivity, and implementation of telemedicine programs in different countries. We compared research performance between countries with or without implementation of telemedicine programs**.** We analyzed the scientific collaboration of technology manufactures between countries with or without implementation of telemedicine programs.

To address differences in research productivity, collaboration, and scientific and economic impact, we analyzed research performance indicators of all publications indexed in Scopus (Table 1).

For statistical analyses we used correlation analysis, general linear models, and logistic regression performed in STATA (StataCorp http://www.stata.com) and SAS 9.4 (SAS Institute Inc., Cary NC, USA). Significance was analyzed at 95% confidence level.

Results

We identified 71,245 publications related to telemedicine, only 0.8% of which addressed a policy of telehealth care delivery. A percentage of publications that addressed a policy of telehealth care increased to 2.6% in 2018 (Fig. 1). The authors of the publications related to telemedicine were affiliated with 160 institutions. Scholarly output related to telemedicine did not substantially differ among the 160 institutions. However, five institutions—Harvard Medical School, VA Medical Center, University of Pennsylvania, Massachusetts General Hospital, and University of Calgary—contributed 13% of all publications that addressed a policy of telehealth care.

The United States, United Kingdom, Australia, Canada, and Germany contributed 57% of all publications related to telemedicine. The United States, United Kingdom, Canada, Australia, and India contributed 77% of all publications that addressed a policy of telehealth care. Research performance in the field of telemedicine was highest in North American and European countries and lowest in South American and African countries (Table 2). Research performance in the field of telemedicine was highest in countries with high income and lowest in countries with low income (Table 3). Implementation of teleradiology, teledermatology, telepathology, and telepsychiatry was more common in countries with high and upper middle income than in countries with low income (Fig. 2).

Scholarly output related to telemedicine was positively correlated with countries’ total health expenditure (% GDP) (correlation coefficient 0.62). We found no correlation between the scholarly output related to telemedicine and countries’ total population; physician, nurses or hospital bed density per 10,000 population; life expectancy at birth; mobile-cellular subscriptions; or the percentage of Internet users.

We analyzed scholarly output related to telemedicine among countries with various national policies, strategies, funding, and

Table 1
Indicators of research productivity, collaboration, scientific and economic impact.

Indicator	Measured entity characteristic	Definition
Scholarly Output	Productivity	The number of indexed in Scopus publications.
Field-Weighted Citation Impact*	Scientific impact	The number of citations received by an entity's publications compared with the average number of citations received by all other similar publications in the data universe.
Citations	Scientific impact	The number of citations received by an entity's publications.
Citations per Publication	Scientific impact	The average citation impact of the publications as the number of an average received citations
Outputs in Top Citation Percentiles (top 10%)	Scientific impact	The number of publications in the top 1%, 5%, 10% or 25% of the most-cited publications
Outputs in Top Views Percentiles (top 10%)	Scientific impact	The number of publications are in the top 1%, 5%, 10% or 25% of the most-viewed publications
Publications in Top Journal Percentiles (top 10% by CiteScore Percentile)	Scientific impact	The number of publications are in the top 1%, 5%, 10% or 25% of the most-cited journals indexed by Scopus
Topic Prominence	Scientific impact	Is an indicator of momentum/movement or visibility of a particular topic. Topic Prominence is comprised of three metrics –recent citation counts, recent views counts, and journal impact (CiteScore). These three metrics are computed and then normalized using log transforms and standard deviations. The results are then combined as a weighted average.
Academic-Corporate Collaboration (%)	The degree of collaboration between academic and corporate affiliations	Proportion of co-authored publications across the academic and corporate, or industrial sectors
International Collaboration (%)	The degree of collaboration between international coauthors	Proportion of internationally co-authored publications
Patent-Citations Count (patent office: All Patent Offices)	Economic Impact	The total count of patent citations received by the entity
Patent-Citations per Scholarly Output (patent office: All Patent Offices)	Economic Impact	The average patent-citations received per 1000 scholarly outputs published by the entity
Citing-Patents Count (patent office: All Patent Offices)	Economic Impact	The count of patents citing the scholarly output published by the entity
Patent-Cited Scholarly Output (patent office: All Patent Offices)	Economic Impact	The count of scholarly output published by the entity (e.g. a university) that have been cited in patents.
Mass Media (Print)	Social impact	Total count of mass media mentions for Institutions and Countries
Field-Weighted Mass Media (Print)	Social impact	The number of media mentions received by an entity's publications compared with the average number of media mentions received by all other similar publications in the data universe
Media Exposure	Social impact	The ratio of media mentions weighted by type of publication, demographics and audience reach.
Topic Prominence	Scientific impact	Is an indicator of momentum/movement or visibility of a particular topic. Topic Prominence is comprised of three metrics –recent citation counts, recent views counts, and journal impact (CiteScore). These three metrics are computed and then normalized using log transforms and standard deviations. The results are then combined as a weighted average.
h-indices	Productivity and scientific impact	A balance between the productivity (Scholarly Output) and citation impact (Citation Count) of an entity's publications

* A Field-Weighted Citation Impact of 1.00 indicates that the entity's publications have been cited exactly as would be expected based on the global average for similar publications; the Field-Weighted Citation Impact of "World", or the entire Scopus database, is 1.00.

Table 2
Scholarly output related to telemedicine by geographic regions, responders to the WHO Global Observatory for eHealth.

Regions	Number of countries*	Publications related to telemedicine	
		Mean**	Standard deviation
North America	2	13,073	13,113.3
Europe	37	825	1340.6
South Asia	4	711	1352.7
East Asia	17	658	1051.1
Western Pacific	5	502	1038.0
Central Asia	12	203	332.5
Middle East	13	148	185.8
South America	26	85	204.4
Africa	38	47	89.4

* Countries who responded to the WHO survey.
** Sorted from the largest to the smallest number of publications.

Table 3
Scholarly output related to telemedicine by the World Bank Income ranking of countries.

World Bank Income Country Ranking	Number of countries*	Publications related to telemedicine	
		Mean**	Standard deviation
High income	56	1224	3149.8
Upper-middle-income	38	213	426.5
Lower-middle-income	36	126	453.4
Low-income	23	17	18.1

* Countries who responded to the WHO survey.
** Sorted from the largest to the smallest number of publications.

legal frameworks for telemedicine (Table 4). The average scholarly output related to telemedicine was much larger in countries with versus without the National eHealth policy or strategy, established public or commercial funding of eHealth, government supported Internet sites in multiple languages, training of healthcare providers, and training of human resources for health information systems (Table 4). Scholarly output related to telemedicine was much larger in countries with versus without a legal framework

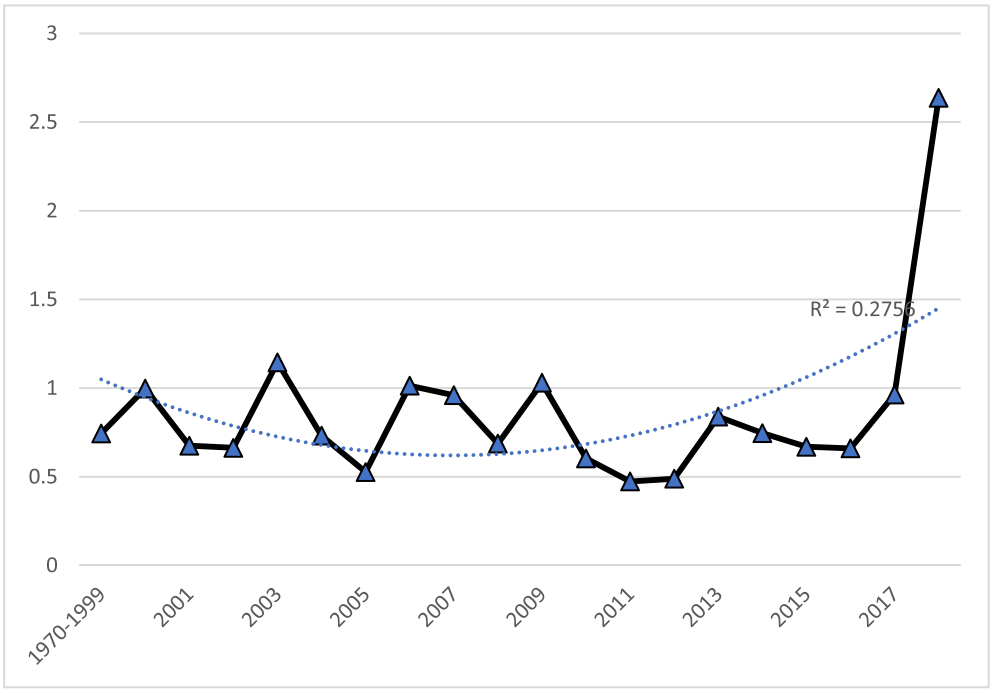

Fig. 1. Percentage of publications that addressed a policy of telehealthcare among the total publications realted to telemedicine (Scopus data, September 2018).

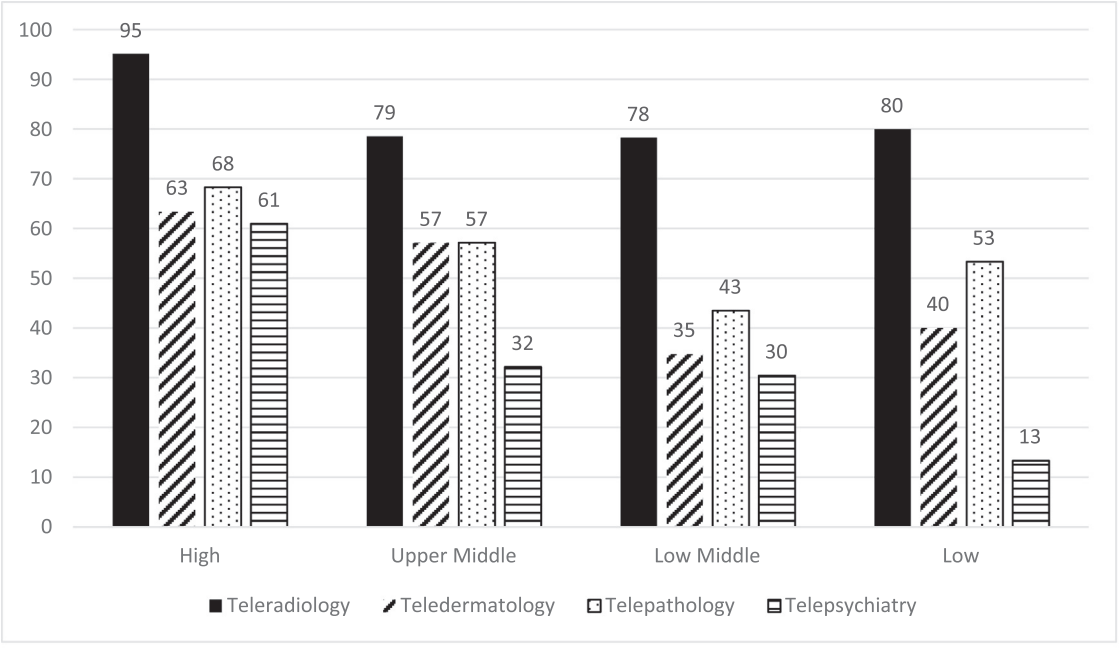

Fig. 2. Percentage of countries with telemedicine implementation by the World Bank Income ranking of countries (the data from the WHO Global Observatory for eHealth).

supporting the utilization of telemedicine (Table 4). As expected, scholarly output related to telemedicine was much larger in countries with implemented teleradiology, teledermatology, telepathology, telepsychiatry, and remote patient monitoring (Table 4). Scholarly output related to telemedicine was similar in countries with versus without national identification management systems, national electronic health records, medical billing systems, or state governing of big data in the health sector (data not shown).

We analyzed the odds of implemented telemedicine programs in countries with versus without national policies, strategies, funding, and legal frameworks for telemedicine (Table 5). We found that not all policies were associated with the higher odds of implementation of telemedicine programs. National universal health coverage policy or strategy, eHealth capacity building, legislation that allows patients access to their electronic health records, and supply chain management information systems supported by information and communication technologies were consistently associated with the implementation of all examined telemedicine programs (Table 5). National health information system policy or strategy, specific funding of eHealth, legislation protecting

Table 4
Scholarly output related to telemedicine in countries with or without specific national policies, strategies, funding, and legal framework for telemedicine.

Country policy	Countries with listed policy		Countries without listed policy	
	Publication mean	Standard deviation	Publication mean	Standard deviation
eHealth foundations				
National eHealth policy or strategy	897	2914.9	198	484.3
Funding sources for eHealth: Public funding	756	2563.2	29	34.8
Funding sources for eHealth: Private or commercial funding	1052	3334.7	353	1091.7
Policy or strategy on multilingualism	579	806.2	289	1019.2
Government-supported Internet sites in multiple languages	1064	3172.9	141	403.7
eHealth capacity building				
Health sciences students – Pre-service training in eHealth	751	2592.2	23	34.7
Health professionals – In-service training in eHealth	742	2566.0	60	150.4
Legal frameworks for eHealth – purpose of policy or legislation				
Defines medical jurisdiction, liability or reimbursement of eHealth services such as telehealth	1236	3668.7	311	944.0
Addresses patient safety and quality of care based on data quality, data transmission standards or clinical competency criteria	1125	3222.1	121	357.0
Protects the privacy of personally identifiable data of individuals irrespective of whether it is in paper or digital format	660	2490.4	271	698.4
Protects the privacy of individuals' health-related data held in electronic format in an EHR	955	2954.3	146	398.7
Governs the sharing of digital data between health professionals in other health services in the same country through the use of an EHR	1345	3590.3	154	356.9
Governs the sharing of personal and health data between research entities	1162	3385.5	158	406.3
Allows individuals electronic access to their own health-related data when held in an EHR	1518	3906.4	203	441.8
Allows individuals to demand their own health-related data be corrected when held in an EHR if it is known to be inaccurate	1315	3716.3	265	902.1
Allows individuals to demand the deletion of health-related data from their EHR	766	1077.2	630	2663.8
Allows individuals to specify which health-related data from their EHR can be shared with health professionals of their choice	823	1408.3	542	2862.9
Telehealth programs implemented in countries				
Teleradiology	712	2511.51	132	222.1603
Teledermatology	1036	3118.202	175	607.2163
Telepathology	948	2974.301	181	640.6667
Telepsychiatry	1383	3547.168	116	228.2036
Remote patient monitoring	1067	3111.168	140	595.4557
Information and communication technologies assisted functions				
Supply chain management information systems	588	1178.6	112	209.7
Human resources for health information systems	443	1014.2	186	339.8

the privacy of personally identifiable data, legislation addressing international data sharing, legislation that governs the use of the national electronic health records (EHR) system and the national EHR system identification management systems, and the policy of big data collection and analytics were not associated with higher odds of implementation of all examined telemedicine programs (Table 5). eHealth capacity building demonstrated the strongest association with the implementation of telemedicine (Table 5). All countries reporting the implementation of teleradiology also reported the implementation of policies governing the use of big data in the health sector (Table 5).

The implementation of specific policies was associated with the implementation of specific telemedicine programs. For instance, countries with a national telehealth policy or strategy had higher odds of implemented teledermatology and telepathology but not teleradiology or telepsychiatry (Table 5). Public funding of eHealth was associated with the higher odds of implemented telepsychiatry but not teledermatology, telepathology, or teleradiology (Table 5). Legislations that addressed patient safety and quality of care based on data quality, data transmission standards or clinical competency criteria were associated with higher odds of implemented teledermatology, telepathology, or telepsychiatry but not teleradiology (Table 5). When we restricted the analysis to low income countries only, country response data was sparse due to poor response rate and low rates of the implementation of telemedicine. Government-supported Internet sites in multiple languages, student training in eHealth, and electronic medical billing systems were associated with higher odds of implemented teleradiology and telepathology, and national identification management systems were associated with higher odds of implemented telepsychiatry. Inconsistency in the association with specific policies suggested that specific legislation activities contributed but did not solely determine the implementation of telemedicine programs.

We analyzed the role of industry in the implementation of telemedicine across countries. The majority of the publications addressed the use of telecommunications technology including smartphones; image devices; computer interfaces and networks; audiovisual equipment; and monitoring devices or medical devices including defibrillators, pacemaker, biosensors, and insulin pumps. We identified 43 telecommunications technology or medical device manufacturing companies that contributed to more than 90% of the publications related to telemedicine.

We analyzed the research performance and impact of these manufacturing companies (Table 6). Microsoft USA, Intel, Samsung, Siemens, and Philips Health Tech had the largest scholarly output while Microsoft USA, Google Inc., Nokia, and Medtronic, Inc. had the highest research impact according to the field-weighted citation impact (Table 6). Microsoft USA, Intel, Google Inc., Nokia, and Johnson & Johnson had the highest research impact according to the h5-index (Table 6). Nokia, Johnson & Johnson, Hoffmann-La Roche Inc., and Boston Scientific Corporation had the largest percentage of the publications resulting from international collaborations (Table 6). Microsoft USA, Stryker Corporation, Edwards Lifesciences, Boston Scientific Corporation, and Adobe Systems Incorporated had the largest percentage of the publications resulting from collaboration with academic authors (Table 6).

Table 5
Implementation of telemedicine in countries with versus without legislation and policies supporting eHealth (the data from the WHO Global Observatory for eHealth).

Country policy or legislation	Teledermatology	Telepathology	Teleradiology	Telepsychiatry
	Odds ratios (95%CI) of implemented telemedicine in countries with versus without listed policy			
eHealth foundations				
National universal health coverage policy or strategy	**4.5(1.3;15.4)**	**3.1(1.0;9.4)**	**3.7(1.1;13.2)**	**5.9(1.3;27.8)**
National eHealth policy or strategy	1.9(0.8;4.4)	1.7(0.7;3.8)	2.1(0.6;7.0)	1.8(0.8;4.3)
National health information system (HIS) policy or strategy	0.9(0.4;2.1)	1.3(0.6;3.0)	1.6(0.5;4.9)	0.7(0.3;1.6)
National telehealth policy or strategy	**3.7(1.3;10.2)**	**3.6(1.2;10.6)**	4.7(0.6;37.0)	1.8(0.7;4.5)
Funding sources for eHealth: Public funding	1.8(0.6;5.6)	2.5(0.8;7.5)	3.2(0.8;12.0)	**5.3(1.1;25.0)**
Funding sources for eHealth: Private or commercial funding	1.9(0.8;4.4)	**3.8(1.6;9.0)**	1.8(0.5;6.4)	1.6(0.7;3.6)
Funding sources for eHealth: Public-private partnerships	2.0(0.9;4.6)	1.4(0.6;3.1)	1.0(0.3;3.5)	1.4(0.6;3.3)
Policy or strategy on multilingualism	**2.7(1.0;7.0)**	1.3(0.5;3.3)	NE	**4.8(1.8;12.8)**
Government-supported Internet sites in multiple languages	2.0(0.8;4.7)	1.8(0.8;4.3)	2.6(0.7;10.1)	2.1(0.9;5.1)
eHealth capacity building				
Health sciences students – Pre-service training in eHealth	**9.0(1.9;43.5)**	**12.2(2.6;58.8)**	**6.2(1.6;23.8)**	**11.0(1.4;90.9)**
Health professionals – In-service training in eHealth	**6.8(1.4;32.3)**	**4.9(1.2;19.6)**	**11.4(2.9;45.5)**	**8.5(1.1;71.4)**
Legal frameworks for eHealth				
Defines medical jurisdiction, liability or reimbursement of eHealth services such as telehealth	**2.4(1.0;5.5)**	1.1(0.5;2.5)	4.0(0.8;19.2)	1.7(0.7;3.8)
Addresses patient safety and quality of care based on data quality, data transmission standards or clinical competency criteria	**3.2(1.4;7.3)**	**2.2(1.0;5.1)**	1.2(0.4;4.0)	**2.6(1.1;5.9)**
Protects the privacy of personally identifiable data of individuals irrespective of whether it is in paper or digital format	1.5(0.4;5.3)	0.5(0.1;2.2)	2.4(0.6;10.5)	1.2(0.3;4.5)
Protects the privacy of individuals' health-related data held in electronic format in an EHR	**3.9(1.7;9.2)**	**2.9(1.3;6.8)**	2.6(0.8;8.1)	**4.3(1.7;10.6)**
Governs the sharing of digital data between health professionals in other health services in the same country through the use of an EHR	**3.0(1.3;6.9)**	**4.0(1.6;9.6)**	3.2(0.8;12.2)	**2.5(1.1;5.8)**
Governs the sharing of digital data between health professionals in health services in other countries through the use of an EHR	1.7(0.7;4.2)	1.7(0.7;4.3)	2.7(0.6;12.8)	1.6(0.6;3.9)
Governs the sharing of personal and health data between research entities	**3.4(1.5;8.0)**	**2.4(1.0;5.6)**	2.7(0.8;9.4)	**3.0(1.3;7.1)**
Allows individuals electronic access to their own health-related data when held in an EHR	**3.7(1.5;9.1)**	**2.7(1.1;6.7)**	**8.3(1.0;66.7)**	**2.4(1.0;5.5)**
Allows individuals to demand their own health-related data be corrected when held in an EHR if it is known to be inaccurate	**2.3(1.0;5.5)**	2.1(0.9;5.1)	4.0(0.8;19.2)	2.1(0.9;4.8)
Allows individuals to demand the deletion of health-related data from their EHR	1.6(0.6;4.3)	1.1(0.4;3.0)	4.4(0.5;35.7)	2.0(0.7;5.2)
Allows individuals to specify which health-related data from their EHR can be shared with health professionals of their choice	**2.4(1.0;5.7)**	**2.4(1.0;6.1)**	3.4(0.7;16.7)	**3.2(1.4;7.7)**
Governs civil registration and vital statistics	2.9(0.5;15.6)	3.6(0.7;20.0)	**10.1(2.0;52.6)**	0.9(0.2;4.1)
Governs National EHR system identification management systems	1.2(0.4;3.7)	2.3(0.7;7.4)	3.8(0.9;15.4)	1.6(0.5;5.6)
Electronic health records (EHR) **country overview**				
National EHR system	**2.2(1.0;4.7)**	1.0(0.5;2.2)	1.8(0.5;5.7)	**2.3(1.0;5.1)**
Legislation governing the use of the National EHR system	1.0(0.3;3.2)	1.5(0.5;4.8)	2.5(0.4;16.7)	1.2(0.4;3.8)
Information and communication technologies assisted functions				
Electronic medical billing systems	**3.2(1.2;8.5)**	**4.7(1.7;12.5)**	**4.4(1.3;14.7)**	2.2(0.8;5.9)
Supply chain management information systems	**5.5(1.9;15.6)**	**5.1(1.8;14.1)**	**5.0(1.4;17.5)**	**3.7(1.2;11.1)**
Human resources for health information systems	**5.1(1.5;16.9)**	**2.8(1.0;8.2)**	0.9(0.2;4.5)	2.6(0.8;8.6)
Governing the use of big data in the health sector	2.8(0.9;8.5)	2.9(0.9;9.7)	NE	1.6(0.6;4.5)
Governing the use of big data by private companies	2.3(0.6;9.7)	1.0(0.3;4.0)	NE	2.3(0.6;8.7)

NE- not estimable because all countries with implemented telemedicine program also had listed implemented policy.

We analyzed the research performance and impact of the authors collaborating with information technology industry (Table 7). We identified 10 companies collaborating with academic authors that had the highest research impact according to the Field-Weighted Citation Impact (Table 7). Google, Microsoft USA, and Nokia collaborated with the authors that had the highest research impact according to h5-index (Table 7).

The number of publications coauthored with industry and the number of authors collaborating with industry were larger in countries with versus without implemented remote patient monitoring, teledermatology, telepathology, and telepsychiatry but not teleradiology. We analyzed the total number of institutions in each country collaborating with 43 telecommunication technology or medical devices manufacturing companies. Countries with versus without implemented remote patient monitoring had more institutions collaborating with Microsoft, Johnson & Johnson, Philips, Intel, Siemens, General Electric, Medtronic, and Toshiba (Fig. 3). Countries with versus without implemented teledermatology had more institutions collaborating with Microsoft, Johnson & Johnson, Philips, and Siemens (Fig. 4). Countries with versus without implemented telepathology had more institutions collaborating with Microsoft, Philips, and Siemens (Fig. 5). Countries with versus without implemented telepsychiatry had more institutions collaborating with Microsoft, Johnson & Johnson, Philips, Intel, Siemens, Google, General Electric, Medtronic, Toshiba, Samsung, Carl Zeiss, Sony, and Boston Scientific (Fig. 6). The number of institutions that collaborated with industry did not differ in countries with versus without implemented radiology (Fig. 7).

Discussion

We identified economic, legal, and research performance factors associated with the worldwide implementation of telemedicine programs. We found that policy related publications constitute only a small, though growing, proportion of all publications related to telemedicine. We found that only 3% of research institutions (all from the US and Canada) contributed to 13% of all publications that addressed a policy of telehealth care and that only

Table 6
Research performance of industry entities contributing to the research related to telemedicine (exported from Scopus and SciVal in September 2018).

Industry	Scholarly Output	Citations	Field-Weighted Citation Impact (rank)	Outputs in Top Citation Percentiles (top 10%)	Publications in Top Journal Percentiles (top 10% by CiteScore Percentile)	Citations per Publication	International Collaboration (%) (rank)	Academic-Corporate Collaboration (%)	h5-index
Microsoft USA	7610	103,777	3.79(1)	23.90%	39.80%	13.6	51.00%(8)	85.40%	136
Intel	5980	34,385	1.88(15)	12.50%	29.70%	5.8	31.70%(27)	69.80%	82
Samsung	5404	31,128	1.32(27)	11.10%	32.70%	5.8	25.10%(31)	74.20%	71
Siemens	5189	26,228	1.37(26)	11.60%	31.90%	5.1	42.10%(16)	72.90%	69
Philips HealthTech	4310	29,734	1.41(23)	17.10%	37.80%	6.9	47.60%(10)	82.80%	71
Google Inc.	3743	51,509	3.78(2)	19.50%	37.80%	13.8	38.40%(20)	76.10%	88
Nokia	3617	33,498	2.43(3)	13.70%	32.00%	9.3	66.20%(1)	62.60%	87
General Electric	3145	16,593	1.49(21)	11.20%	31.40%	5.3	32.30%(26)	55.90%	56
Toshiba	2782	10,325	1.2(28)	7.30%	18.90%	3.7	17.30%(39)	47.10%	40
Johnson & Johnson	2117	23,900	2.15(10)	26.70%	41.50%	11.3	62.70%(3)	66.70%	78
Bayer	1984	24,633	2.38(5)	30.90%	44.80%	12.4	64.00%(2)	72.50%	75
Mitsubishi Electric Corporation	1622	3559	0.95(35)	3.80%	13.30%	2.2	16.40%(41)	41.40%	24
GE Healthcare	1544	12,354	1.4(24)	20.80%	43.10%	8	42.10%(15)	82.40%	52
Agilent Technologies	851	11,735	1.99(14)	24.00%	43.00%	13.8	41.60%(18)	68.30%	56
Spectrum Health	832	7301	2.01(13)	20.10%	33.40%	8.8	19.20%(37)	1.30%	38
3M	792	4056	1.03(31)	9.20%	28.90%	5.1	22.10%(32)	53.00%	33
Sony	738	3999	1.55(20)	10.90%	34.00%	5.4	37.40%(21)	64.20%	32
Medtronic, Inc.	666	10,420	2.39(4)	25.90%	32.40%	15.6	52.10%(6)	80.20%	53
Allergan Incorporated	515	5841	1.82(16)	28.20%	34.70%	11.3	43.10%(13)	77.10%	40
Hoffmann-La Roche Inc.	473	9247	2.29(9)	35.60%	46.50%	19.5	58.10%(4)	60.90%	62
Carl Zeiss SMT AG	466	2988	1.65(18)	16.40%	29.10%	6.4	45.10%(12)	63.70%	32
Stryker Corporation	462	1069	0.65(39)	8.10%	22.10%	2.3	19.50%(35)	93.10%	16
AIR LIQUIDE	434	1697	0.95(34)	9.90%	40.00%	3.9	42.60%(14)	70.30%	22
Canon	345	1377	0.95(36)	6.50%	24.60%	4	18.00%(38)	62.60%	19
Edwards Lifesciences	231	2904	1.79(17)	31.00%	46.80%	12.6	36.40%(24)	91.30%	32
Apple	216	1312	2.3(7)	16.30%	50.00%	6.1	33.80%(25)	82.40%	20
Nikon Corporation	212	776	0.86(37)	8.90%	23.90%	3.7	20.30%(33)	56.60%	15
Boston Scientific Corporation	203	3235	2.3(8)	34.60%	32.10%	15.9	56.70%(5)	84.70%	30
Dell	179	1302	1.4(25)	15.80%	29.30%	7.3	41.90%(17)	75.40%	25
Adobe Systems Incorporated	150	1456	2.1(12)	18.10%	45.50%	9.7	25.30%(30)	84.00%	28
Hewlett Packard Enterprise	150	281	1.46(22)	10.80%	27.30%	1.9	47.30%(11)	69.30%	8
Varian Medical Systems	143	986	1.6(19)	14.20%	19.70%	6.9	37.10%(22)	78.30%	16
Olympus Corporation	135	573	0.64(40)	12.60%	29.70%	4.2	19.30%(36)	76.30%	14
OMRON Corporation	115	1545	2.36(6)	12.80%	22.40%	13.4	27.00%(29)	80.00%	14
Konica Minolta Inc	94	456	1.09(30)	13.30%	25.90%	4.9	16.00%(42)	73.40%	11
Eastman Kodak	83	355	0.66(38)	7.50%	36.40%	4.3	16.90%(40)	44.60%	17
Fujifilm Corporation	76	665	1(32)	16.40%	27.90%	8.8	29.00%(28)	69.70%	14
B Braun Melsungen	71	259	0.51(41)	9.10%	15.90%	3.6	36.60%(23)	78.90%	10
St. Jude Medical, Inc. USA	31	205	1.1(29)	22.20%	32.10%	6.6	51.60%(7)	77.40%	10
Microchip Technology Inc.	15	4	0.2(43)	0.00%	0.00%	0.3	20.00%(34)	6.70%	1
Abbott Diagnostics	13	21	0.27(42)	0.00%	23.10%	1.6	38.50%(19)	38.50%	3
Linde AG	10	22	1(33)	0.00%	0.00%	2.2	50.00%(9)	40.00%	2
C R Bard Inc	4	52	2.11(11)	0.00%	0.00%	13	0.00%(43)	75.00%	3

Table 7
Research performance of the top authors affiliated with industry entities contributing to the research related to telemedicine (exported from Scopus and SciVal in September 2018).

Industry	Field-Weighted Citation Impact	Citations per publication	h5-index
Google	7.8 ± 20.0	30.2 ± 92.1	14.0 ± 10.7
Microsoft USA	4.4 ± 6.8	15.5 ± 23.5	20.7 ± 11.3
Sony	3.1 ± 5.6	9.8 ± 27.2	5.3 ± 6.6
Nokia	2.7 ± 3.4	9.3 ± 19.2	11.6 ± 8.6
Intel	2.6 ± 2.5	6.6 ± 6.5	10.4 ± 7.2
Agilent Technology	2.5 ± 6.9	15.4 ± 39.2	6.2 ± 7.8
Bayer	2.4 ± 3.7	11.9 ± 16.0	9.7 ± 8.0
Samsung	2.2 ± 2.8	7.8 ± 10.8	10.0 ± 8.3
Hoffmann-La Roche	2.2 ± 2.3	21.6 ± 23.2	10.1 ± 8.7
Apple	2.1 ± 4.4	4.9 ± 17.3	5.5 ± 5.6

The results are presented as means± standard deviations of each indicator.

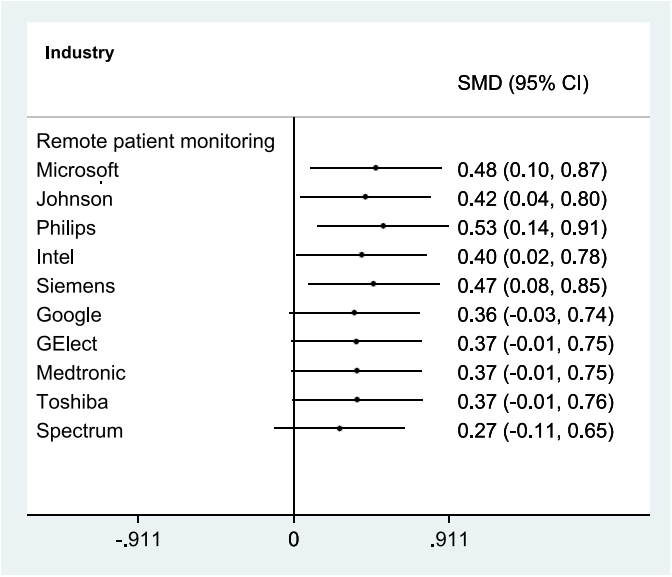

Fig. 3. The number of collaborating with industry institutions in countries with versus without implemented remote patient monitoring (the data exported from SciVal in September 2018 was combined with the WHO Global Observatory for eHealth). SMD- standard mean difference with 95% confidence intervals (CI).

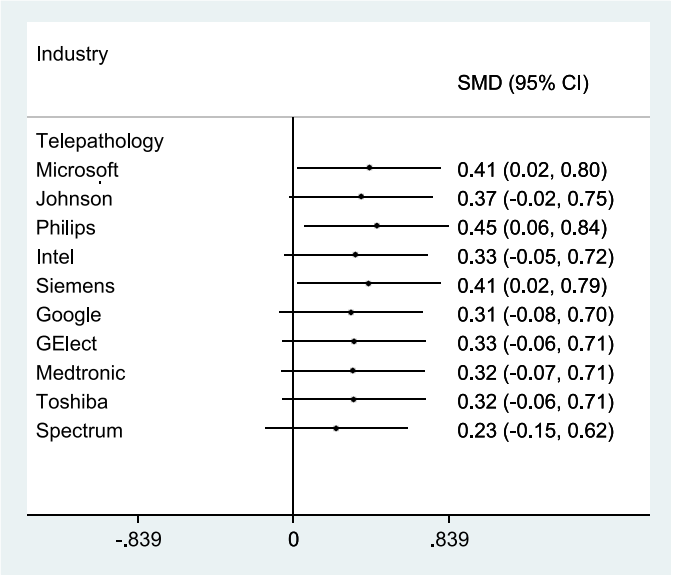

Fig. 5. The number of collaborating with industry institutions in countries with versus without implemented telepathology (the data exported from SciVal in September 2018 was combined with the WHO Global Observatory for eHealth). SMD- standard mean difference with 95% confidence intervals (CI).

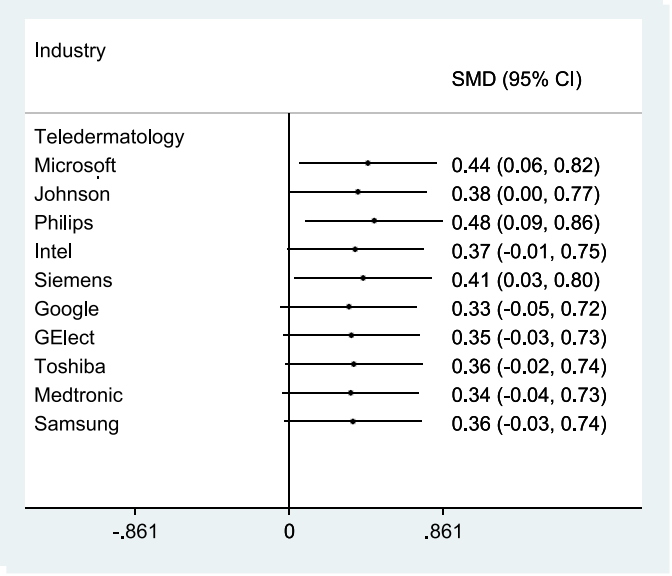

Fig. 4. The number of collaborating with industry institutions in countries with versus without implemented teledermatology (the data exported from SciVal in September 2018 was combined with the WHO Global Observatory for eHealth). SMD- standard mean difference with 95% confidence intervals (CI).

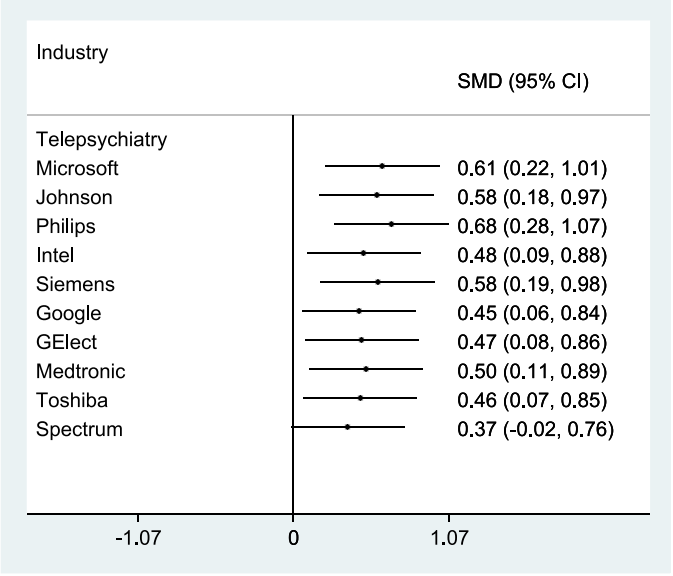

Fig. 6. The number of collaborating with industry institutions in countries with versus without implemented telepsychiatry (the data exported from SciVal in September 2018 was combined with the WHO Global Observatory for eHealth). SMD- standard mean difference with 95% confidence intervals (CI).

a few developed countries contributed to 57% of all publications related to telemedicine. Higher country income was positively associated with telemedicine related scholarly output, research performance, and the implementation of telemedicine programs. The only healthcare economic factor positively associated with the scholarly output was country's total health expenditure. Physician, nurse, or hospital bed density and population size and life expectancy were not correlated with scholarly output. This lack of correlation suggests low research activity in countries with limited access to healthcare. Such countries would benefit the most from the implementation of telemedicine and universal healthcare access [40].We found a positive association between countries' scholarly output and the implementation of telemedicine programs, and the implementation of national policies, funding, capacity building of eHealth, and supply chain management information systems supported by information and communication technologies. We found that research activity of the information and communication technology industry was positively associated with the implementation of telemedicine programs. We identified several industry companies with the best research performance and impact that are associated with the implementation of telemedicine programs.

Our findings are in concordance with the published expert surveys suggesting that a national Information and Communication Technology policy, national e-Health policy, and infrastructure are positively associated with telemedicine capability [42,45]. Our findings about the importance of eHealth capacity building are in

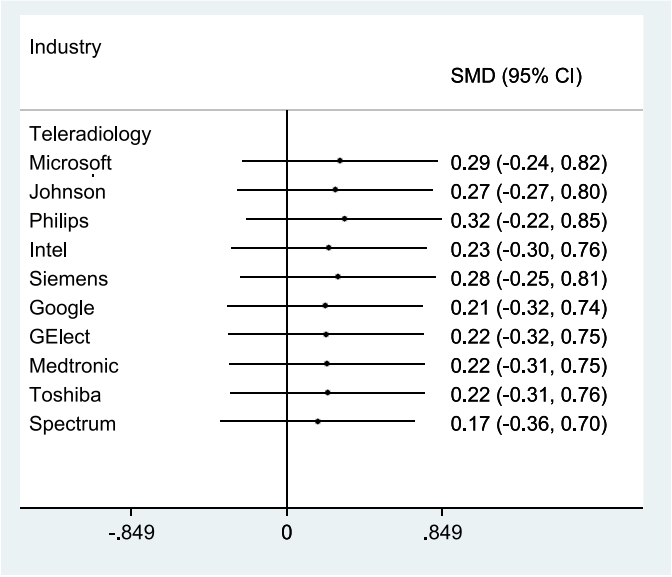

Fig. 7. The number of collaborating with industry institutions in countries with versus without implemented radiology (the data exported from SciVal in September 2018 was combined with the WHO Global Observatory for eHealth).
SMD- standard mean difference with 95% confidence intervals (CI).

concordance with the published literature reviews that identified technically challenged staff and poor computer skills by healthcare providers and patients as some of the most important barriers in the implementation of telemedicine [26]. Other reviews emphasized the role of adequate reimbursement, commercial models, and the investment in information technology infrastructure but did not examine the role of specific technology companies contributing to the implementation of telemedicine [26,46,47].

Our analysis identified few leading industry entities contributing to the research and implementation of telemedicine. This information can assist stakeholders in the developing the most effective evidence-based legal framework and high impact collaborative research aimed at the implementation of telemedicine in developing countries [25,48–52].

Our results suggest that the number of publications coauthored with industry and the number of coauthors collaborating with industry were larger in countries with versus without established remote patient monitoring activities, teledermatology, telepathology, and telepsychiatry. Previous publications have also suggested that developing countries have adopted some aspects of legal framework for eHealth but lack well-designed collaborative research with information technology industry [25,30,50,52–58]. Recently adopted legislation efforts in developing countries address instant access to healthcare, compatibility and sharing of medical records, continuity of healthcare across various settings, provider responsibility for accurate diagnoses, and the best available treatment during face-to-face contact with patients and subsequent remote consultations [59-61]. Legal frameworks in developed countries also address the importance of credentialing health care professionals in information technology applications, licensing of healthcare providers across state and country borders, ethical principles of telemedicine, informed consent of patients, corporate medicine that prohibits the employment of doctors by information technology corporations, and liability of healthcare professionals for any treatment-related harms for patient privacy, health, and wellbeing [43,62–65].

There have been very few telemedicine liability cases in the US [66–70]. Cases have addressed the prohibited prescription of any dangerous drug including abortion-inducing drugs without face-to-face examination, or fraudulent distribution of controlled substances outside the usual course of professional practice [66–70]. Telemedicine legal claims are likely to increase as telemedicine becomes a standard clinical practice. Evolving legislation and policy efforts including the implementation of the Interstate Medical Licensure Compact and Tele-Med Act should overcome legal problems and liability concerns [63–65,71–74].

Our work has many limitations. Our exploratory analyses of combined databases lack temporality evaluation and address associations rather than cause and effect relationships. We focused our analyses on the WHO survey on eHealth with a response rate of 64% [28]. Survey data does not provide information about the intensity and saturation of the implemented telemedicine programs as well as success of the implemented programs in relation to the improved patient outcomes [28]. We restricted our analysis to a limited number of telemedicine programs and did not contact experts about implementation of other telemedicine programs including telecardiology, tele-dentistry, or tele-surgery.

There are important potential confounding factors affecting the detected associations. Utilization of telemedicine is more common in geographically large countries with dispersed populations, subnational jurisdictions, and federated health systems and policies [27].We did not analyze subnational variability in the implementation of telemedicine since state level policy information was available only for the US [71,72,74,75]. State research support is not specific to telemedicine, for instance, high income countries have more scholars who publish in peer reviewed indexed journals across a broad range of scholarly fields including telemedicine. Multinational country-level analysis of existing data sources has inherent limitations in assessing variable saturation of implemented telemedicine programs within different healthcare facilities and by individual providers. For instance, a previous survey of the availability and use of telecommunications technologies to support health care delivery conducted by the European Commission and the Organization for Economic Cooperation and Development Working Group found that only seven countries reported availability of videoconferencing in at least three-quarters of acute care facilities [27].

We restricted our analyses of research performance to the data exported from EMBASE, Scopus, and SciVal and did not link each retrieved record with other citation databases including Web of Science database [76,77]. All available research performance and impact metrics are based on a distribution of the available publications rather than valid measures of the patient outcomes [78,79]. We did not analyze the quality of publications related to telemedicine interventions or policies nor did we conduct comparative analyses of legislations related to eHealth and telemedicine [41,80,81]. Although we did not restrict our analyses to publications in English, we did not conduct additional searches for publications in other languages. We relied on Elsevier taxonomy and indexing in searches for the publications related to telemedicine, telehealth care delivery and policy, and Elsevier metrics of research performance [44]. Implementation of telemedicine in space travel, military populations, correctional facilities, during pandemics, or using drones for medical supply delivery was beyond our scope [82–86].

Despite multiple limitations, we believe that the results from our exploratory analyses can support evidence-based research and policy decisions aimed at the implementation of telemedicine programs worldwide. Our work has policy implications. All stakeholders should work together to harmonize legal, regulatory, ethical, and policy aspects of telemedicine [42,63,65,72,74,81,87–95]. International telemedicine policies and strategies are needed for international capacity building, reimbursement policies, and secure data sharing policies [26,41,46,96]. Worldwide information and communication industry penetration is faster than medical industry penetration with disruptive innovative business models [97–102]. Industry-driven implementation of telemedicine programs should be based on such innovative business models. In-

ternational telemedicine policies should be developed to overcome unnecessary country specific regulations and ensure patient access to healthcare.

We identified research implications of our results. Collaborative research with industry involvement and state support is associated with the implementation of telemedicine programs. Such collaborative research efforts should be focused on populations with limited geographical access to good healthcare [28]. Although there is a great deal of randomized experiments on comparative effectiveness and safety of particular telehealth applications, no international databases or registries collect information about patient outcomes in clinical settings. Therefore, the evaluation of comparative effectiveness, safety and efficiency of technological applications in real-life settings is largely unknown. Future efforts should be directed toward consistent collection and routine analysis of patient outcomes after telemedicine interventions. Future research should address multinational requirements for effective and safe telemedicine applications [80,103–122]. Telemedicine applications should be implemented for real-world evidence analyses including patient-generated data, disease registries focused on patient-centered outcomes, electronic health records, and billing documents [123,124].

Our work has practice implications. International endorsement of evidence-based guidelines recommending telemedicine by professional societies in developing countries may prompt the implementation of specific telemedicine programs [125–128]. New evidence-based clinical guidelines related to telemedicine should be developed based on high quality evidence reviews, in collaboration with professional societies from developing countries, and with industry support [129–133]. Industry involvement in multinational supply chain management information systems, support of human resources, and proper training of healthcare providers would ensure the seamless implementation of telemedicine programs across borders [97,134–146].

In conclusion, research performance, training of medical students and healthcare professionals, and collaboration with technology industry demonstrated the strongest association with implementation of telemedicine. Future efforts should be directed toward consistent collection and routine analysis of patient outcomes after telemedicine interventions. International legislation is needed for telemedicine capacity building, reimbursement policies, and secure data sharing policies. International collaborative research and policy efforts are needed to implement telemedicine programs with universal access to the best possible healthcare for populations in need.

Author statements

Funding

None

Competing interests

There are no financial or other relations that could lead to a conflict of interest.

Ethical approval

This work does not require an ethical approval.

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