Mammography: density equalizing mapping of the global research architecture

Dörthe Brüggmann[1,2,3], Matthias Grimstein[2], Christine Solbach[1], Doris Klingelhöfer[2], Michael H. K. Bendels[2], Jenny Jaque[3], David A. Groneberg[2]

[1]Department of Gynecology and Obstetrics, Goethe-University, Frankfurt, Germany; [2]Institute of Occupational, Social and Environmental Medicine, Frankfurt, Germany; [3]Department of Obstetrics and Gynecology, Keck School of Medicine, University of Southern California, California, USA

Correspondence to: Prof. Dörthe Brüggmann, MD, PhD. Department of Gynecology and Obstetrics, Goethe-University, Theodor Stern Kai 7, 60590 Frankfurt, Germany. Email: prevention@uni-frankfurt.de.

Background: Since mammography belongs to the most important preventive techniques in modern medicine, this study maps the related worldwide research output, which encompasses quantitative and qualitative aspects of the scientific activity and socio-economic features.

Methods: The New Quality and Quantity Indices in Science (NewQIS) computing platform identified all mammography-specific articles in the Web of Science within two time periods, from 1900 to 2014 (P1) and from 2015 to 2020 (P2), a combination of density-equalizing mapping projections (DEMP) and socio-economic benchmarking was applied for analysis.

Results: A total of 13,629 articles were retrieved. 8,744 articles were identified in P1 and 4,885 in P2. More than 100 articles were published annually since the 1980s. Regarding productivity and collaborative efforts, the United States was the leading nation in both evaluation periods. In our socioeconomic analysis, it was also ranked at the first place in P1 [72.68 mammography-related publications per GDP/capita (RGDP)]. The US was followed by the UK and Germany in P1 and by UK and India in P2. When population sizes were related to mammography research activities, Scandinavian countries and the Netherlands showed the highest research activity in P1 (e.g., Sweden: 31.89 publications per 1 million inhabitants). Gender analysis illustrated a relative dominance of female researchers in most countries with the exception of Japan.

Conclusions: The global mammography research activity over the last century is paralleled by strong international collaborative efforts and follows largely economic figures and prevalence rates but displays distinct differences in comparison to the research landscape of other biomedical entities.

Keywords: Density equalizing map; mammography; spatiotemporal analysis

Introduction

In females, breast cancer is the most frequently diagnosed cancer and cause of death worldwide. The highest incidence rates are documented for high resource countries such as the United States and Canada as well as regions such as Western and Northern Europe (1-3). In contrast to Asia and sub-Saharan Africa, where the incidence numbers are the lowest, researchers associate epidemiological differences with distinct cultural, environmental and reproductive factors linked to the industrialization level such as lactation, fat intake, or fewer pregnancies (1,4). Overall, known risk factors are well characterized; they include family or personal history of breast cancer, high breast density or genetic mutations among others (1,4).

Prevention is extremely important in the field of breast

cancer medicine. Breast cancer screening aims at reducing mortality and morbidity associated with advanced disease through early detection (5). The most common screening procedure is standard mammography, which was first described by the German Otto Kleinschmidt in 1927. In 1969, Gallager and Martin described the usefulness of mammography in detection of early stages of breast cancers coining the "concept of minimal breast cancer" (6,7). Moscowitz published preliminary results for mammography as a screening tool (8). Today, mammography is offered by organized programs or through opportunistic screening, which typically provides exams upon request or embedded in routine health care (5). In November 2014, the International Agency for Research on Cancer (IARC) assessed the benefits and adverse effects of the different screening methods (5). They reported advantages for women aged 50 to 69 years due to mammographic screening (5). By contrast, randomized, controlled trials generally did not show a reduction in breast-cancer mortality by regular breast self-examination (5).

From a global viewpoint, standard mammography may be regarded as one of the most important procedures to prevent death and disability from breast cancer. To date the debate about the harms and benefits of mammographic screening is ongoing. Numerous new topics have to be discussed such as tumor over-diagnosis and—treatment related to screening and the role of mammography in a modern era of increased public scrutiny and novel diagnostic tools such as tomosynthesis (9,10). Hence, the international community needs to find answers to relevant questions in the area of "mammography", which underpins the necessity for further research. Since global research funds are limited, the assessment of the scientific performance is a prerequisite for the reasonable distribution of monetary support and human resources. In contrast to other areas of radiology (11-15) and the field of breast cancer research (16,17), where 180,126 articles were published between 1945 and 2008, no concise studies have been reported on global activities of mammography research. To address this shortcoming, we used the New Quality and Quantity Indices in Science (NewQIS) computing platform (16-19) whose research aims are manifold and reviewed in great detail elsewhere (20). In short, this tool provides objective, transparent and reliable analyses of bibliometric parameters to assess the evolution of scientific productivity over distinct periods of time. Individual scientists or clinician-scientists, policy makers or funding institutions can utilize this data to match the past and current scientific output with future research interests or funding endeavors to address obvious needs. In this particular study, we employed the NewQIS platform to analyze the worldwide scientific productivity related to mammography with regard to (I) quantitative and qualitative assessments, (II) chronologic and geographic developments as well as (III) socio-economic, collaboration and gender aspects.

Methods

NewQIS study

The NewQIS computing platform was created by a multidisciplinary group of scientists to analyze scientific productivity regarding to a specific topic in a highly standardized approach as well as to visualize the results in global maps (20). Since its establishment in 2008/2009 NewQIS features have been discussed for three times by Nature and Nature Index blogs (21).

Data source

The high-quality Web of Science (WoS, Thomson Reuters) database allowed the quantitative analysis of research activity (e.g., the number of mammography-specific publications) as well as the assessment of qualitative aspects (e.g., citation rates) (22-24) by its unique citation report function.

Search strategy

We performed a TITLE search using the following search term: TITLE=(*mammogra* OR (*tomosynthes* AND (breast OR mamma). Only documents classified as ARTICLES were included. Our search covered the two evaluation periods P1 from 1900 to 2014 and P2 from 2015 to 2020 in order to analyze the overall as well as the recent publication output.

Data analysis and categorization

The bibliographic details of mammography-related publications were sorted after retrieval of the file metadata and analyzed according to numerous criteria of interest (24-28). These criteria included year of publication, subject categories, and citations among others. From these data, country-specific h-indices were constructed. The h-index was developed by Jorge Hirsch in 2005 aiming to gauge scientific quality based on citations that an author's body of

work receives (29,30). Here, we used a modified h-index to estimate the recognition of the country-specific research output among the scientific community (31,32). The mammography-related articles could be attributed to more than one subject area. Hence, we could observe percentages exceeding 100% when we displayed the subject area analysis of all identified articles per country.

Density-equalizing map projections

A NewQIS core technique entails the generation of world maps depicting aspects of the investigated research output using density-equalizing map projections (DEMP) (32-34). All bibliometric metadata were transferred into a Microsoft® Access® database, which represented the core data source for all analyses. Based upon the density-equalizing principle algorithm created by Gastner and Newman (35), the variables of interest were visualized by density-equalizing map projections specifically for every country. Anamorphic cartograms were built utilizing the software "ArcGIS Cartogram" geoprocessing tool (https://www.arcgis.com). In these maps, territories of countries publishing mammography-related research were separated from each other and resized in proportion to selected criteria of interest such number of articles or citation counts.

Economic analysis

In order to provide more meaningful findings, we related each country's economic and demographic capabilities to its achievement in publishing. Gross domestic product (GDP) and population size were used as proxy measures for economic and human resources a country can utilize to create articles on mammography. We sourced economic key figures from the *Central Intelligence Agency World Factbook* and the *International Monetary Fund* (14,36). We related the publication output of the analyzed countries to their GDPs in 2015 for P1 and to their most recent GDPs in 2017 for P2.

Analysis of mammography research collaborations

To analyze global research collaborations, we downloaded the mean affiliations of authors listed in the identified articles. For each article, we extracted the countries of the respective co-authors, who collaborated for the article. These relationships were quantified (a collaboration between two authors was counted only once) and a circle diagram was created (37,38). Vectors depict the number of

joint publications between co-authors by their width and shade of grey.

Gender assessment

Author gender was analyzed. Therefore, we utilized a specific tool embedded in the NewQIS platform that collects first names and links names to the respective gender. This instrument was developed by the original creators of the NewQIS platform as an adaptive tool, which continuously integrates new data during each analysis. In our study, we identified all first names of authors publishing on mammography. An algorithm matched this collection with our source database so names were categorized into male, female, unknown and not assignable. Names of the last two categories (e.g., quoted as initials) were manually analyzed based on websites, corresponding addresses, and social networks. Only countries were considered where more than 60 authors as well as more than 50% of all authors were identified by gender.

Creation of the key word analysis

Aiming to define research foci in the area of mammography, we analyzed keywords attributed to all identified articles. A keyword needed to be identified at least 10 times to be taken into account. A database of all keywords was computed by the NewQIS platform and downloaded into the VOSviewer (https://www.vosviewer.com). This particular software allows cluster-analysis of the keywords as well as visualization of the results by constructing networks based on co-occurrence data. The clusters were color coded, and the vectors between the key words represent the co-occurrence of keywords in the identified articles.

Results

Density equalizing mapping

From 1900 to 2014 (P1), we identified 8,744 articles (n) that were issued on mammography. 4,885 articles were published from 2015 to 2020 (P2). In total, this added up to 13,629 articles in both evaluation periods.

The first mammography-specific article was published in 1937. For the first 80 years of the 20th century we found a very slow increase of the annual publication output, which exceeded more than 100 annual articles in the later 1980s. From 2011 onwards, more than 400 annual articles were
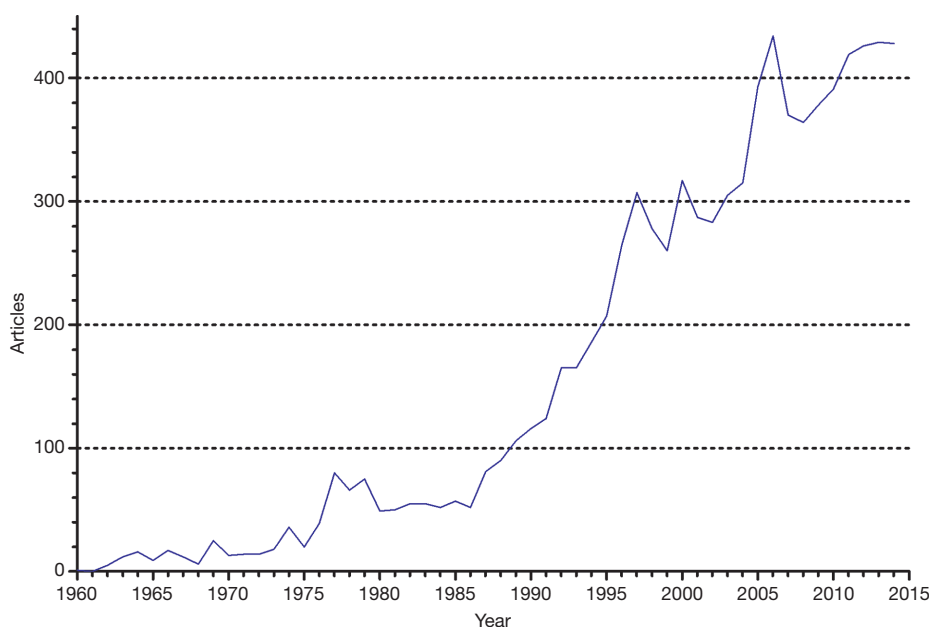
Figure 1 Global mammography research activity (1900 to 2014). Number of published items per year. Before 1960s, no considerable annual publication output was recorded so the graph starts in 1960.

identified (*Figure 1*). In the second evaluation period, the annual article number increased to 1,030 articles in 2015 and 1,029 articles in 2016. Thereafter, the yearly number of articles decreased to 774 in 2017 and has remained below 1,000 per year since then.

In the country specific analyses, authors from 83 countries were identified, who published mammography articles during P1. This number increased to 101 for P2. From the total amount of articles in P1, n=8,513 articles (97.36 %) could be assigned to a country of origin, and in P2, n=4,528 (92.70 %) respectively. US-American authors (authors who stated "United States of America" in their affiliation) were most productive and published the highest number of mammography-related papers in both evaluation periods (P1: n=3,983, P2: 1,683). In P1, they were followed by the United Kingdom (UK) with 711 articles (n), Germany (n=661), Canada (n=507), and Italy (n=425). DEMP analysis demonstrated a distortion of the world map with a distinct focus on Northern America, Western Europe, and Australia (*Figure 2A* and *Table 1*). In P2, the US (n=1,683) was also leading the field of most productive countries and followed by the UK (n=377). In contrast to P1, the order in P2 changed to the following: India (n=273), Australia (n=268), China (n=251). Here, DEMP analysis represented the corresponding increase of publication numbers on mammography in India and China (*Figure 2B*,

Table 1).

The analysis of total mammography-specific citations (c) also demonstrated a leading US-American position in both evaluation periods (P1: c =120,321, P2: c =8311). In P1, the US were followed by Canada (c =18,316) the UK (c =15,996), Sweden (c =13,638) and the Netherlands (c =9,267), (*Figure 3A*). In P2, the US were followed by Australia (c =1916), the UK (c =1,829), the Netherlands (c =1378) and Italy (c =1,064) (*Figure 3B*).

As citation rate (CR), we calculated the citation count per mammography-related articles that authors from a specific country gained (with a minimum of 30 published articles). Here, Sweden was leading in P1 with 43.99 citations per article, followed by Canada (CR =36.13), the Netherlands (CR =31.52) and the US (CR =30.21) (*Figure 4A*). The analysis of P2 showed the following order: Denmark (CR =8.32), the Netherlands (CR =8.06), Austria (CR =7.22), and Portugal (CR =7.22) (*Figure 4B*).

The analysis of the mammography-specific h-index for each country also showed in P1 a leading position of the US and with a modified h-index of 135, followed by Canada (h-index =69), the UK (h-index =56), Sweden (h-index =54), and the Netherlands (h-index =45)]. P2 showed the following ranking: US (h-index =36), Australia (h-index =24), UK (h-index =22), Netherlands (h-index =20), and Italy (h-index =18). We also identified the 16 articles with
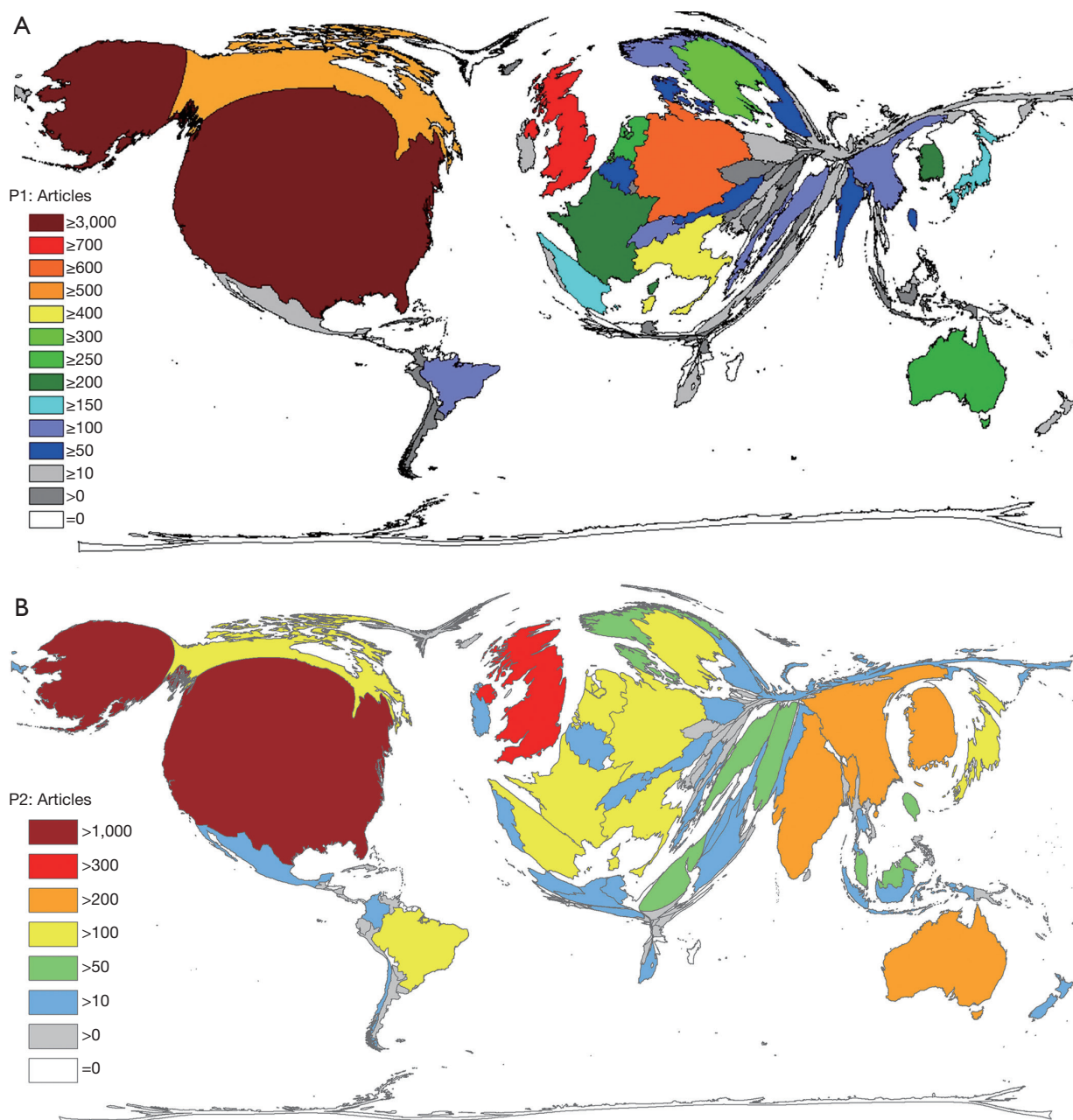
Figure 2 Global scientific productivity on mammography. Density equalizing, colours and territorial sizes indicate numbers of related articles per country. (A) Global mammography research activity from 1900 until 2014 (P1). (B) Global mammography research activity from 2015 until 2020 (P2).

more than 500 citations, which were published from 1985 onwards (*Table 2*).

Socio-economic analysis of mammography research

First, the country-specific mammography publications were related to the population size in million inhabitants (R_{POP}). In P1, Sweden was ranked as the most active high-income country with R_{POP} =31.89 publications per inhabitant, followed by Norway (R_{POP} =28.79), the Netherlands (R_{POP} =17.43), Finland (1 R_{POP} =6.73) and Denmark (R_{POP} =16.01) (*Figure 3*). The US (R_{POP} =12.49) and the UK (R_{POP}

Table 1 Global mammography research productivity in P1 (1900 to 2014) and P2 (2015 to 2020)

Ranking	Time period P1: 1900 to 2014		Time period P2: 2015 to 2020	
	Country	Number of articles	Country	Number of articles
1	United States of America	3,983	United States of America	1,683
2	United Kingdom	711	United Kingdom	377
3	Germany	661	India	273
4	Canada	507	Australia	268
5	Italy	425	China	251
6	Sweden	310	South Korea	220
7	Netherlands	294	Germany	192
8	Australia	292	Italy	175
9	France	234	Netherlands	171
10	South Korea	204	Canada	153

Number of published items per year.

=11.15) were ranked at 11th and 12th position. For China, we identified 0.09 publications per inhabitant while Brazil was characterized by a R_{POP} of 0.62, and India of a R_{POP} of 0.05 mammography-related publications per inhabitant, respectively (*Table 3*). In P2, Norway is ranked first (R_{POP} = 17.12), followed by Sweden (R_{POP} =14.40), Australia (R_{POP} =11.91), the Netherlands (R_{POP} =10.14), and Denmark (R_{POP} =9.53) (*Table 4*).

The gross domestic product (GDP) per capita (R_{pC}) was used as a marker of the economic strength in relation to the population and related to the country-specific mammography publications (R_{GDP}): In P1, the US was at the top position of all analysed high-income countries with an R_{pC} of 72.68 articles, followed by the UK (R_{pC} =18.86), and Germany (R_{pC} =14.79) (*Table 3*). In P2, the leading countries regarding the evaluation of R_{pC} were as follows: India (R_{pC} =47.07), the US (R_{pC} =30.71), and China (R_{pC} =19.46) (*Table 4*).

The countries' GDP in 1,000 billion (bn) USD served as the parameter of the total economic strength. It was related to mammography research output to create the ratio R_{GDP}: In P1, the ranking of high-income countries was led by Greece with an average R_{GDP} of 600.84. It was followed by Sweden with an R_{GDP} of 543.76 and the Netherlands with an R_{GDP} of 339.34. The US was characterized by an R_{GDP} of 228.65 and the UK by an R_{GDP} of 241.43 (*Figure 4*, *Table 3*). For upper middle-income countries, Turkey was ranked first with a R_{GDP} of 148.86. Brazil reached an R_{GDP} of 53.12. The highest ranked lower middle-income country

was India with an R_{GDP} of 29.76 (*Table 3*). In P2, Sweden was the leading country with R_{GDP} =245.57, followed by the upper middle income-country Malaysia (R_{GDP} =211.07), and the lower middle income-country Egypt ranked third (R_{GDP} =202.51) followed by the Netherlands (R_{GDP} =197.37) and Australia (R_{GDP} =185.60) (*Table 4*).

Analysis of mammography research subject areas

The majority of articles (n=3,908) was attributed to the subject area of "Radiology, Nuclear Medicine & Medical Imaging" during both investigated time periods. For P1, it was followed by "Oncology" (n=1,678), "Public, Environmental & Occupational Health" (n=1,018). "Obstetrics & Gynecology" (n=467) and "Surgery" (n=421). A remarkable finding was the prominent increase of articles attributed to "Public, Environmental & Occupational Health" between 1965 and 2014 (*Figure 5A*).

When a country-specific analysis for the subject area activities was performed for the ten most active countries, researchers working in Australia, Canada and the US seemed to focus increasingly on Public health-related topics within mammography research. It was a striking finding that Australia was identified as the only country, in which mammography research was not clearly dominated by the field of "Radiology" (*Figure 5B*).

Key word analysis led to six different clusters of key words (*Figure 6*). Most popular scientific foci of mammography publications were areas such as digital
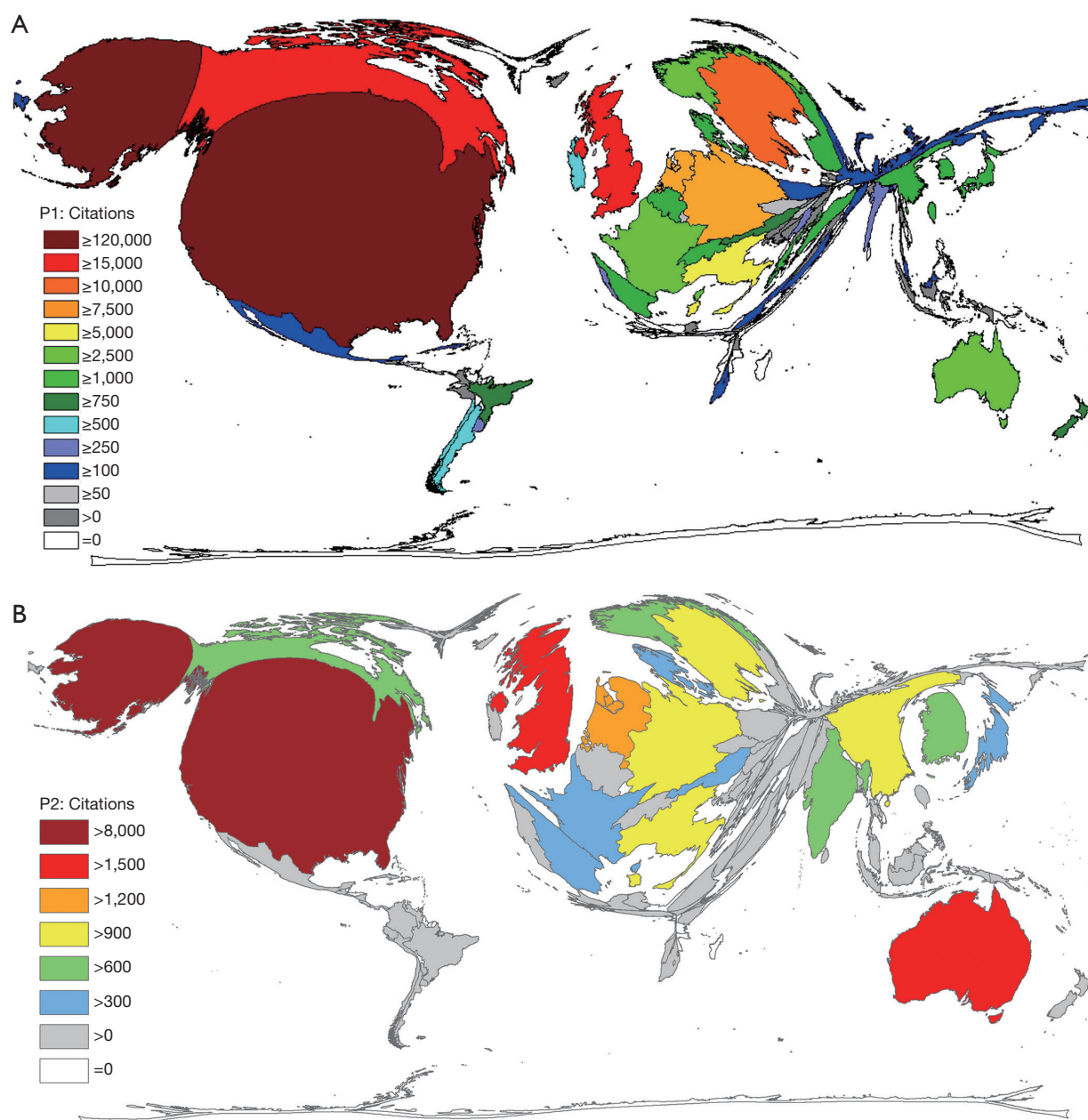
Figure 3 Mammography research quality as represented by the total citation number. (A) Density equalizing map of the total number of mammography-specific citations per country from 1900 until 2014 (P1). (B) Density equalizing map of the total number of mammography-specific citations per country from 2015 until 2020 (P2).

mammography, mammographic density, or screening.

International mammography collaborations

In total, 1,000 international collaborations (11.75% of all articles) were identified in P1 and 905 collaborations

(20.00%) in P2. In P1, US-American authors were involved in 622 collaborative articles with other countries. Researchers based in the UK participated in 206 joint articles and Canadian authors worked on 186 collaborations. These three countries and Norway also led the bilateral collaborations (*Figure* 7). The second evaluation period
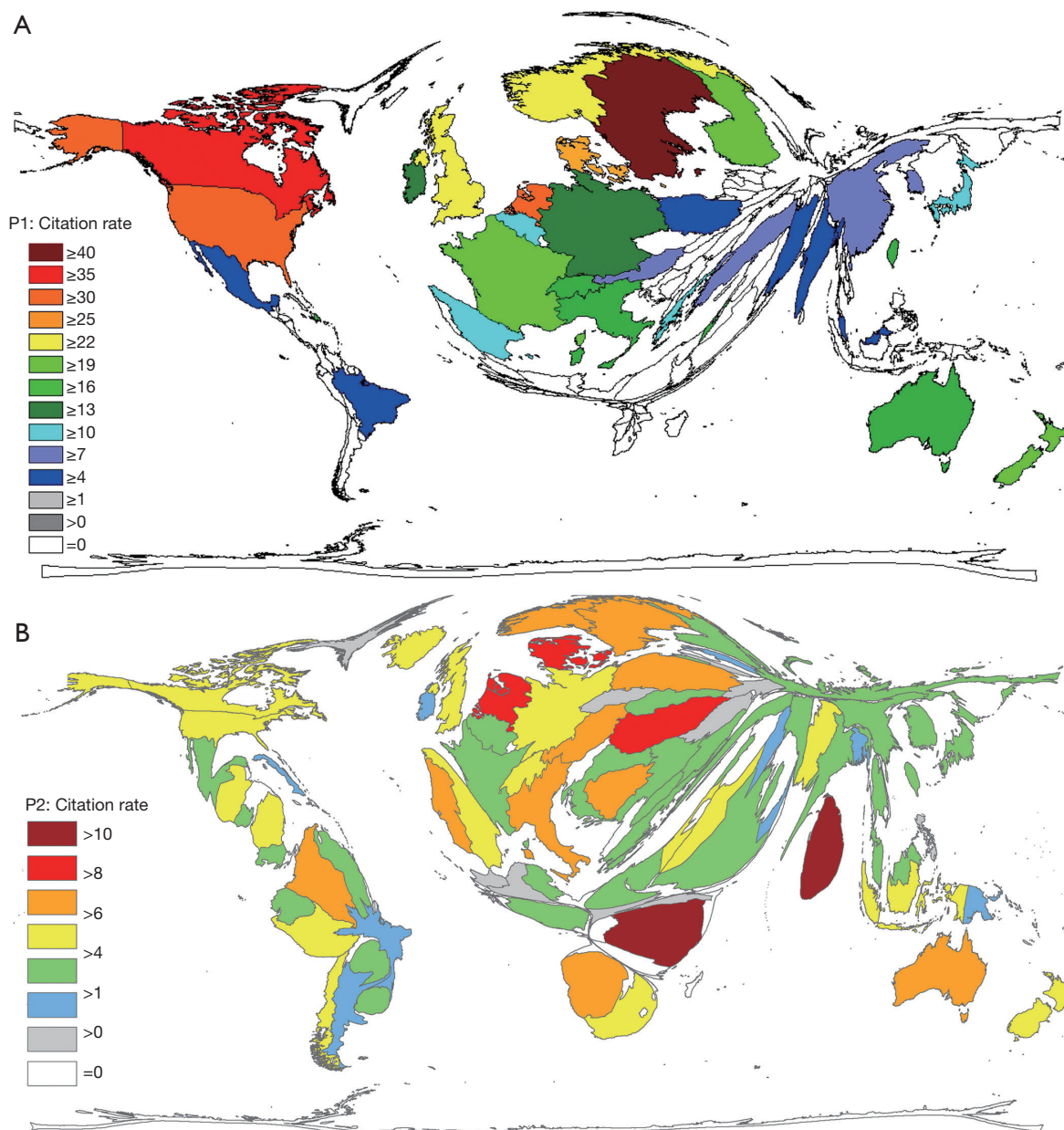
Figure 4 Mammography research quality as represented by the citation rate. (A) Density equalizing map of the total number of mammography-specific citation rates (threshold of 30 publications per country) per country from 1900 until 2014 (P1). (B) Density equalizing map of the total number of mammography-specific citation rates (threshold of 30 publications per country) per country from 2015 until 2020 (P2).

showed the most active partnership on mammography between the US and China with n=67 collaboration articles.

Gender analysis

In order to assess gender aspects in mammography research, subject areas and country were analysed concerning the gender of participating authors. For reasons of validity, this analysis war restricted to P1. Subject areas with a technical focus were found to be dominated by men (i.e., "Engineering" or "Medical Informatics") while female authors dominated the fields of "Public, Environmental and

Table 2 Articles with more than 500 citations, published from 1985 onwards

Title and first author	First author	Publication year	Author country	Citations	Journal
Reduction in mortality from breast-cancer after mass-screening with mammography	Tabar L I	1985	Sweden, France	1,334	*Lancet*
Influence of estrogen plus progestin on breast, cancer, and mammography in healthy postmenopausal women—the Women's Health Initiative Randomized trial	Chlebowski RT	2003	United States	1,033	*JAMA*
American Cancer Society guidelines for breast screening with MRI as an adjunct to mammography	Saslow D	2007	US, UK, Netherlands, Canada	835	*CA Cancer J Clin*
Efficacy of MRI and mammography for breast-cancer screening in women with a familial or genetic predisposition	Kriege M	2004	Netherlands	753	*N Engl J Med.*
Diagnostic performance of digital versus film mammography for breast-cancer screening	Pisano ED	2005	US Canada	717	*N Engl J Med*
Mammographic screening and mortality from breast-cancer—the Malmo mammographic screening trial	Andersson I	1988	Sweden	678	*BMJ*
Breast-cancer screening with mammography—overview of Swedish randomized trials	Nyström L	1993	Sweden	658	*Lancet*
Quantitative classification of mammographic densities and breast-cancer risk—results from the Canadian national breast screening study	Boyd NF	1995	Canada	631	*J Natl Cancer Inst*
Mammographic density and the risk and detection of breast cancer	Boyd NF	2007	Canada	599	*N Engl J Med*
Long-term effects of mammography screening: updated overview of the Swedish randomised trials	Nyström L	2002	Sweden	580	*Lancet*
Update of the Swedish 2-county program of mammographic screening for breast-cancer	Tabàr L	1992	Sweden, UK	558	*Radiol Clin North Am*
Comparison of the performance of screening mammography, physical examination, and breast US and evaluation of factors that influence them: an analysis of 27,825 patient evaluations	Kolb TM	2002	US	556	*Radiology*
Surveillance of BRCA1 and BRCA2 mutation carriers with magnetic resonance imaging, ultrasound, mammography, and clinical breast examination	Warner E	2004	Canada	554	*JAMA*
Analysis of cancers missed at screening mammography	Bird RE	1992	US	533	*Radiology*
Diagnostic accuracy of mammography, clinical examination, US, and MR imaging in preoperative assessment of breast cancer	Berg WA	2004	US, Chile	510	*Radiology*
Mammographic features and breast-cancer risk—effects with time, age, and menopause status	Bryne C	1995	US	506	*J Natl Cancer Inst*

Occupational health" and "Women's Studies" (*Figure 8A*). The majority of female authors involved in mammography research were affiliated with research institutions located in the US (934 female *vs.* 775 male), Canada (113 female *vs.* 83 male) and Australia (63 female *vs.* 53 male). By contrast, male authors dominated the scientific community related to mammography in the UK (105 male *vs.* 95 female), or in Germany (100 male *vs.* 60 female). The highest gender

Table 3 Evaluation period P1 (1900 to 2014): socio-economic analysis of mammography research of the most active regions

Regions	No. of mammography publications	GDP in 1,000 bn USD	GDP per Capita	Population in millions	Publications/ GDP in 1,000 bn USD	Ranking 1	Articles/ GDP per capita	Ranking 2	Publication/ population in millions	Ranking 3
Sweden	310	0.5701	44.7	9.72	543.76	HI2	6.94	HI6	31.89	HI1
Norway	148	0.5002	65.9	5.14	295.88	HI5	2.25	HI15	28.79	HI2
Netherlands	294	0.8664	47.4	16.87	339.34	HI3	6.20	HI8	17.43	HI3
Finland	88	0.2712	40.5	5.26	324.48	HI4	2.17	HI16	16.73	HI4
Denmark	89	0.3408	44.3	5.56	261.15	HI7	2.01	HI19	16.01	HI5
Canada	507	1.789	44.5	34.83	283.40	HI6	11.39	HI5	14.56	HI6
Switzerland	112	0.7121	55.2	8.06	157.28	HI20	2.03	HI18	13.90	HI7
Greece	143	0.238	25.8	10.77	600.84	HI1	5.54	HI11	13.28	HI8
Australia	292	1.444	46.6	22.5	202.22	HI11	6.27	HI7	12.98	HI9
United States	3,983	17.42	54.8	318.9	228.65	HI9	72.68	HI1	12.49	HI10
United Kingdom	711	2.945	37.7	63.74	241.43	HI8	18.86	HI2	11.15	HI11
Austria	83	0.4371	45.4	8.22	189.89	HI13	1.83	HI20	10.10	HI12
New Zealand	41	0.1981	35	4.4	206.97	HI10	1.17	HI23	9.32	HI13
Belgium	97	0.5347	41.7	10.44	181.41	HI15	2.33	HI14	9.29	HI14
Singapore	50	0.3081	81.3	5.56	162.28	HI18	0.62	HI25	8.99	HI15
Germany	661	3.86	44.7	80.99	171.24	HI16	14.79	HI3	8.16	HI16
Ireland	39	0.2464	46.8	4.83	158.28	HI19	0.83	HI24	8.07	HI17
Israel	57	0.3038	33.4	7.82	187.62	HI14	1.71	HI21	7.29	HI18
Italy	425	2.148	34.5	61.68	197.86	HI12	12.32	HI4	6.89	HI19
South Korea	204	1.41	35.4	49.03	144.68	HI21	5.76	HI10	4.16	HI20
Taiwan	89	0.5296	43.6	23.35	168.05	HI17	2.04	HI17	3.81	HI21
France	234	2.847	40.4	66.25	82.19	HI23	5.79	HI9	3.53	HI22
Spain	151	1.407	33	47.73	107.32	HI22	4.58	HI12	3.16	HI23
Turkey	120	0.8061	19.6	81.61	148.86	UMI1	6.12	UMI3	1.47	UMI1
Japan	162	4.616	37.8	127.1	35.10	HI25	4.29	HI13	1.27	HI24
Malaysia	34	0.3269	24.5	30.07	104.01	UMI2	1.39	UMI6	1.13	UMI2
Poland	30	0.5466	24.4	38.34	54.88	HI24	1.23	HI22	0.78	HI25
Brazil	125	2.353	15.2	202.6	53.12	UMI4	8.22	UMI2	0.62	UMI3
Iran	32	0.4041	16.5	80.84	79.19	UMI3	1.94	UMI4	0.40	UMI4
Mexico	31	1.283	17.9	120.28	24.16	UMI5	1.73	UMI5	0.26	UMI5
China	127	10.38	12.9	1355.7	12.24	UMI6	9.84	UMI1	0.09	UMI6
India	61	2.05	5.8	1,236.3	29.76	LMI1	10.52	LMI1	0.05	LMI1

Sources for GDP (Current prices in 1,000 bn US Dollars) and GDP per capita (current prices in 1,000 US Dollars): IMF. HI, high income country; UMI, upper middle-income country; LMI, lower middle-income countries.

Table 4 Evaluation period P2 (2015 to 2020): socio-economic analysis of mammography research of the most active regions

Regions	No. of mammography publications	GDP in 1,000 bn USD	GDP per capita	Population in millions	Articles/GDP in 1,000 bn USD	Ranking 1	Articles/ GDP per capita	Ranking 2	Articles/ population in millions	Ranking 3
Norway	88	0.50	65.90	5.14	175.93	HI4	1.34	HI16	17.12	HI1
Sweden	140	0.57	44.70	9.72	245.57	HI1	3.13	HI12	14.40	HI2
Australia	268	1.44	46.60	22.50	185.60	HI3	5.75	HI4	11.91	HI3
Netherlands	171	0.87	47.40	16.87	197.37	HI2	3.61	HI8	10.14	HI4
Denmark	53	0.34	44.30	5.56	155.52	HI7	1.20	HI18	9.53	HI5
Finland	40	0.27	40.50	5.26	147.49	HI9	0.99	HI21	7.60	HI6
Switzerland	49	0.71	55.20	8.06	68.81	HI19	0.89	HI22	6.08	HI7
United Kingdom	377	2.95	37.70	63.74	128.01	HI11	10.00	HI2	5.91	HI8
Israel	44	0.30	33.40	7.82	144.83	HI10	1.32	HI17	5.63	HI9
Austria	46	0.44	45.40	8.22	105.24	HI13	1.01	HI20	5.60	HI10
United States	1,683	17.42	54.80	318.90	96.61	HI14	30.71	HI1	5.28	HI11
South Korea	220	1.41	35.40	49.03	156.03	HI6	6.21	HI3	4.49	HI12
Canada	153	1.79	44.50	34.83	85.52	HI16	3.44	HI10	4.39	HI13
Belgium	45	0.53	41.70	10.44	84.16	HI17	1.08	HI19	4.31	HI14
Greece	37	0.24	25.80	10.77	155.46	HI8	1.43	HI14	3.44	HI15
Portugal	37	0.23	26.30	10.81	160.87	HI5	1.41	HI15	3.42	HI16
Italy	175	2.15	34.50	61.68	81.47	HI18	5.07	HI5	2.84	HI17
Taiwan	65	0.53	43.60	23.35	122.73	HI12	1.49	HI13	2.78	HI18
Spain	121	1.41	33.00	47.73	86.00	HI15	3.67	HI7	2.54	HI19
Germany	192	3.86	44.70	80.99	49.74	HI21	4.30	HI6	2.37	HI20
Malaysia	69	0.33	24.50	30.07	211.07	UMI1	2.82	UMI5	2.29	UMI1
France	133	2.85	40.40	66.25	46.72	HI22	3.29	HI11	2.01	HI21
Saudi Arabia	41	0.75	52.80	27.34	54.49	HI20	0.78	HI23	1.50	HI22
Japan	135	4.62	37.80	127.10	29.25	HI23	3.57	HI9	1.06	HI23
Turkey	82	0.81	19.60	81.61	101.72	UMI3	4.18	UMI4	1.00	UMI2
Iran	73	0.40	16.50	80.84	180.65	UMI2	4.42	UMI3	0.90	UMI3
Brazil	144	2.35	15.20	202.60	61.20	UMI4	9.47	UMI2	0.71	UMI4
Egypt	58	0.29	11.10	86.89	202.51	LMI1	5.23	LMI2	0.67	LMI1
Mexico	47	1.28	17.90	120.28	36.63	UMI5	2.63	UMI6	0.39	UMI5
India	273	2.05	5.80	1236.30	133.17	LMI2	47.07	LMI1	0.22	LMI2
China	251	10.38	12.90	1,355.70	24.18	UMI6	19.46	UMI1	0.19	UMI6

Sources for GDP (current prices in 1,000 bn US Dollars) and GDP per capita (current prices in 1,000 US Dollars.
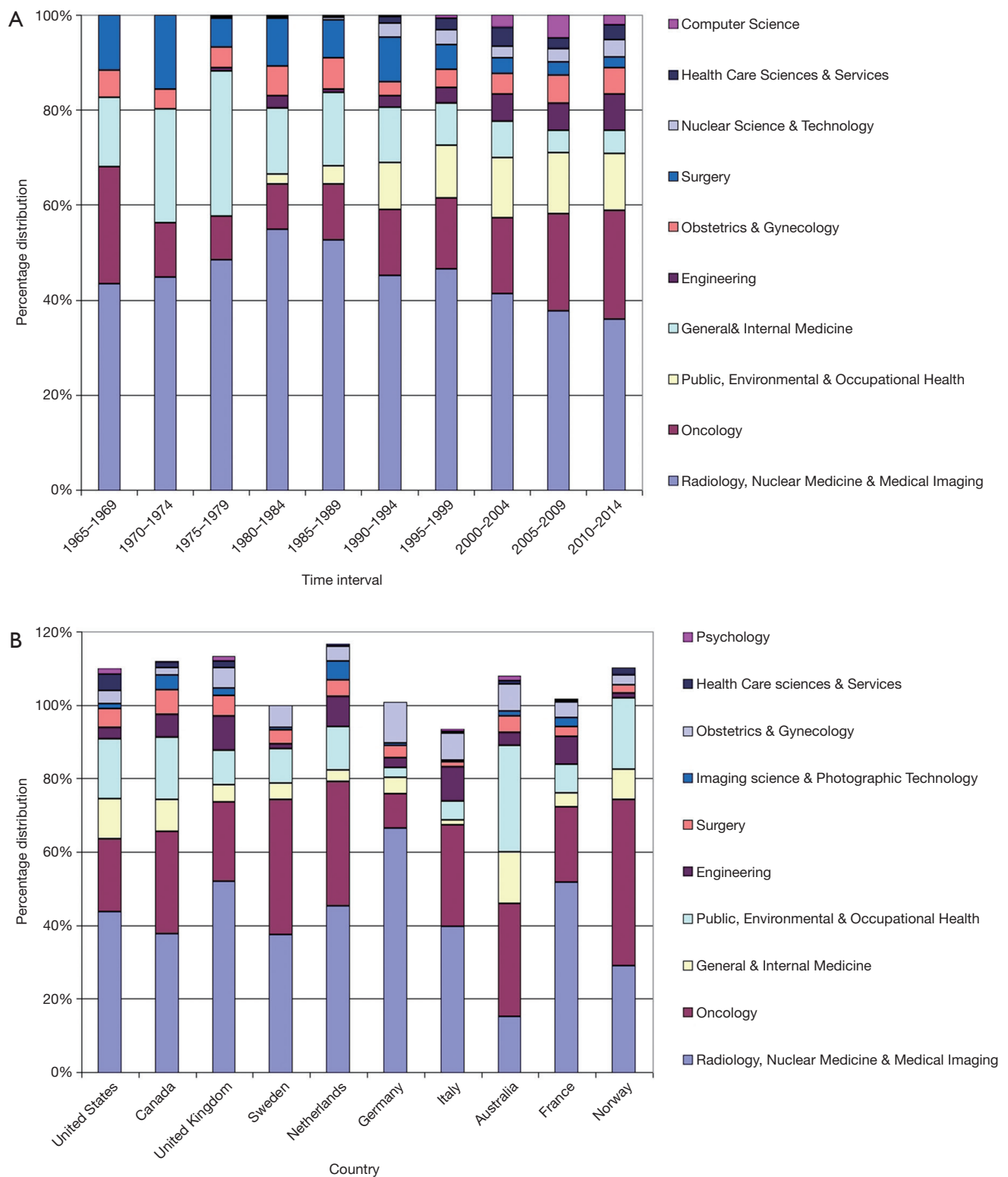
Figure 5 Subject area analysis of mammography research, evaluation period (1900 to 2014). (A) Relative proportions of the most assigned subject areas in 5-year intervals between 1965 and 2014. (B) Relative proportions of the most assigned subject areas in most active countries.
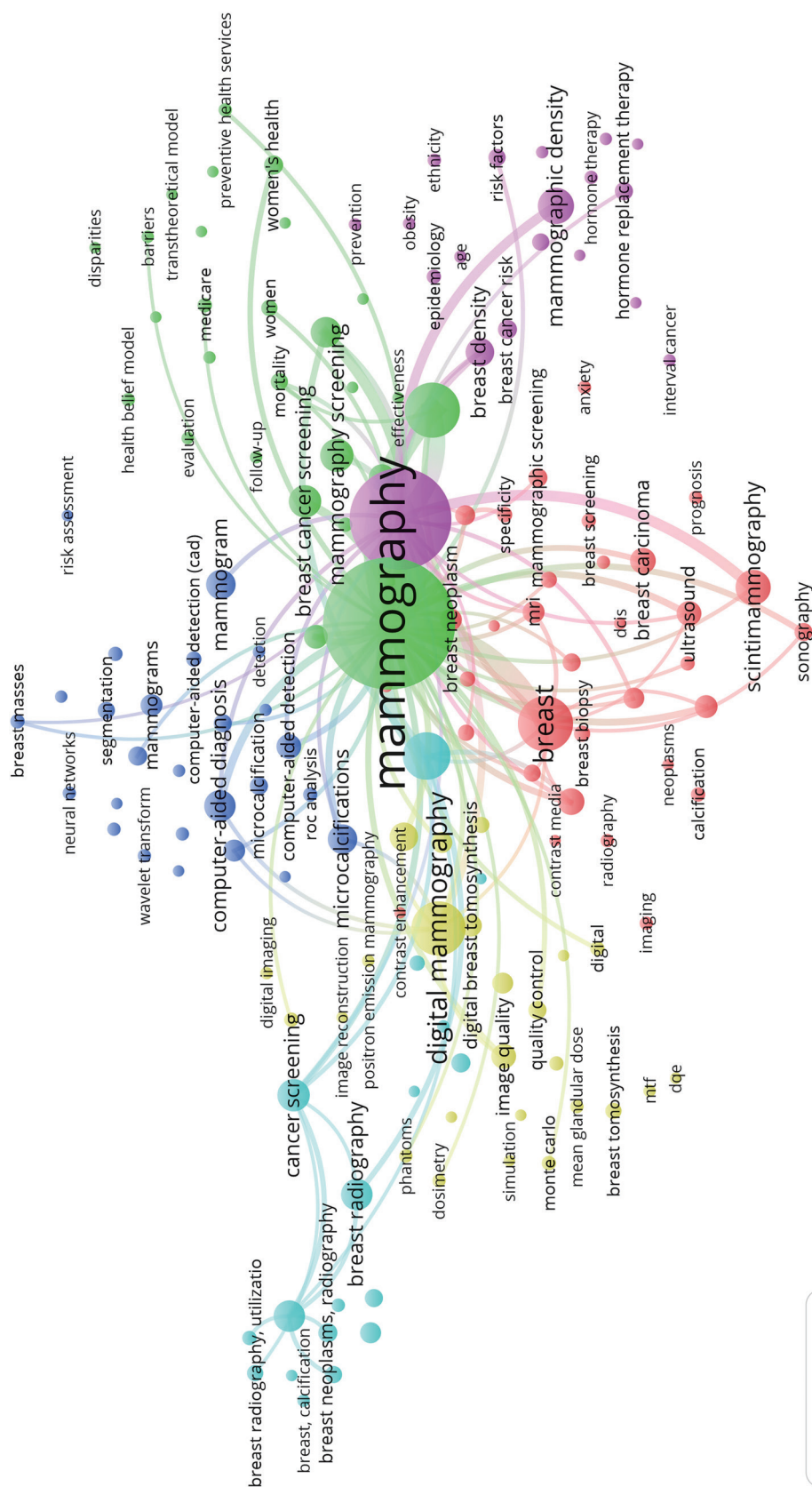
Figure 6 Main key word analysis. Analysis of key word that were attributed for a minimum of 10 times.
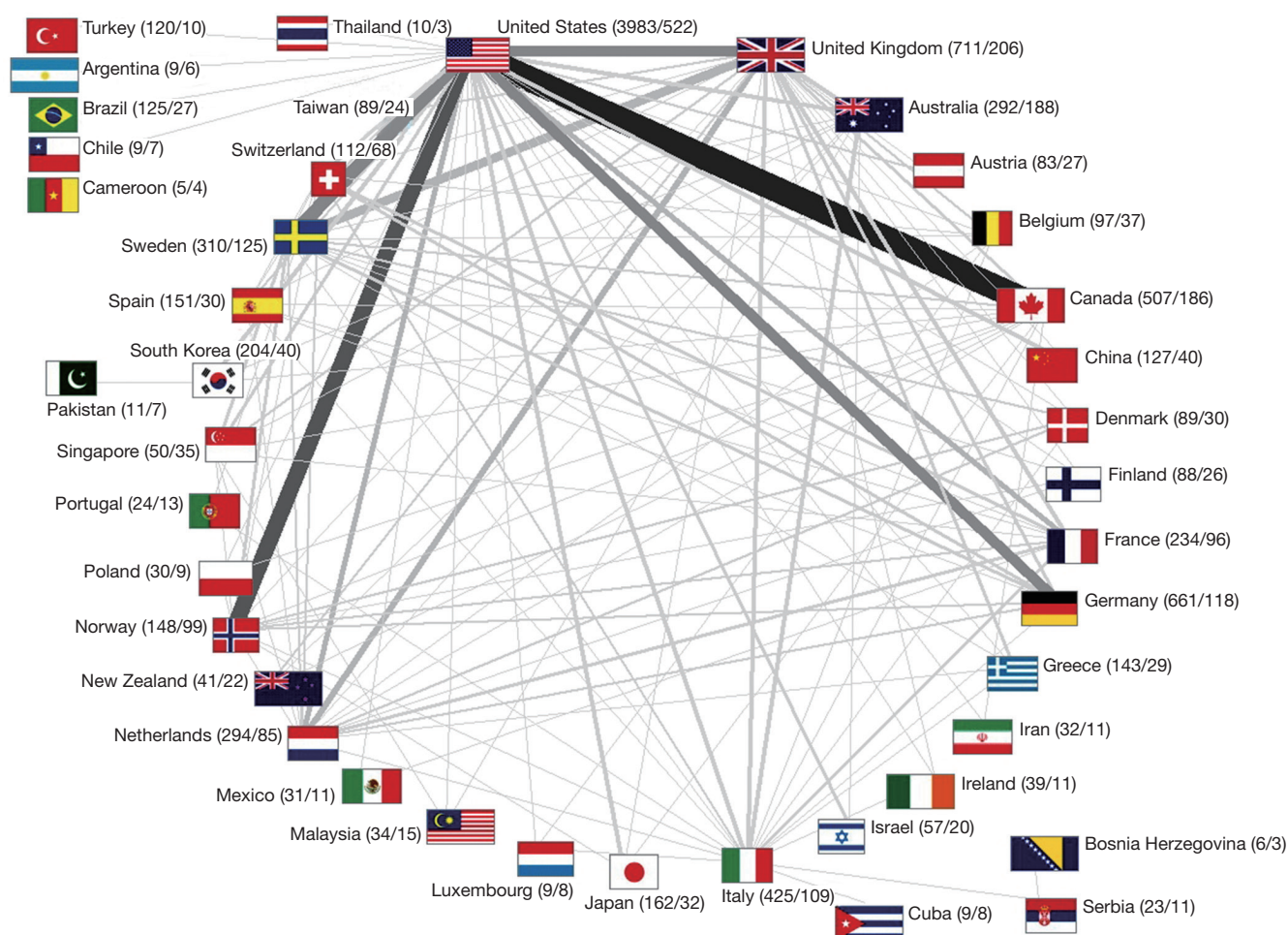
Figure 7 Mammography research collaborations between regions. Greyscale and bar thickness indicate intensity of collaborations, Number in brackets (total publication numbers/number of collaborative publications), Threshold: at least 5 collaborations of a single country, evaluation period (1900 to 2014).

imbalance toward male authors was present in Japan with 113 male *vs.* 39 female authors (*Figure 8B*).

Discussion

In this study, we investigated the global publication output on "mammography" since 1900 and extracted more than 13,000 articles from the WoS to perform an analysis of quantitative and qualitative outcomes, chronological and geographical developments, collaborative networks, socio-economic indicators, and gender aspects in a reliable and standardized way. Despite this strength of being the first study of its kind, some limitations have to be addressed. In this context, the WoS is biased towards journals publishing in English. Therefore, our approach could not identify

all existing articles issued on mammography since 1900, which is illustrated by the fact that the initial report of the technique was not found by our search. Kleinschmidt published his findings in a German book chapter. Since we focused our search on English journals as well as on "articles" to increase the accuracy of the search we did not identify this trailblazer publication but found the first English "mammography" article in 1937. Although an underestimation of non-English articles exists in our study, it might be limited since high quality data is usually published in international journals, indexed in the WoS and therefore included in our search. Further, we gauged the scientific quality of the identified articles by citation-based parameters. This approach has its limitations because citation numbers rather mirror the recognition level of a
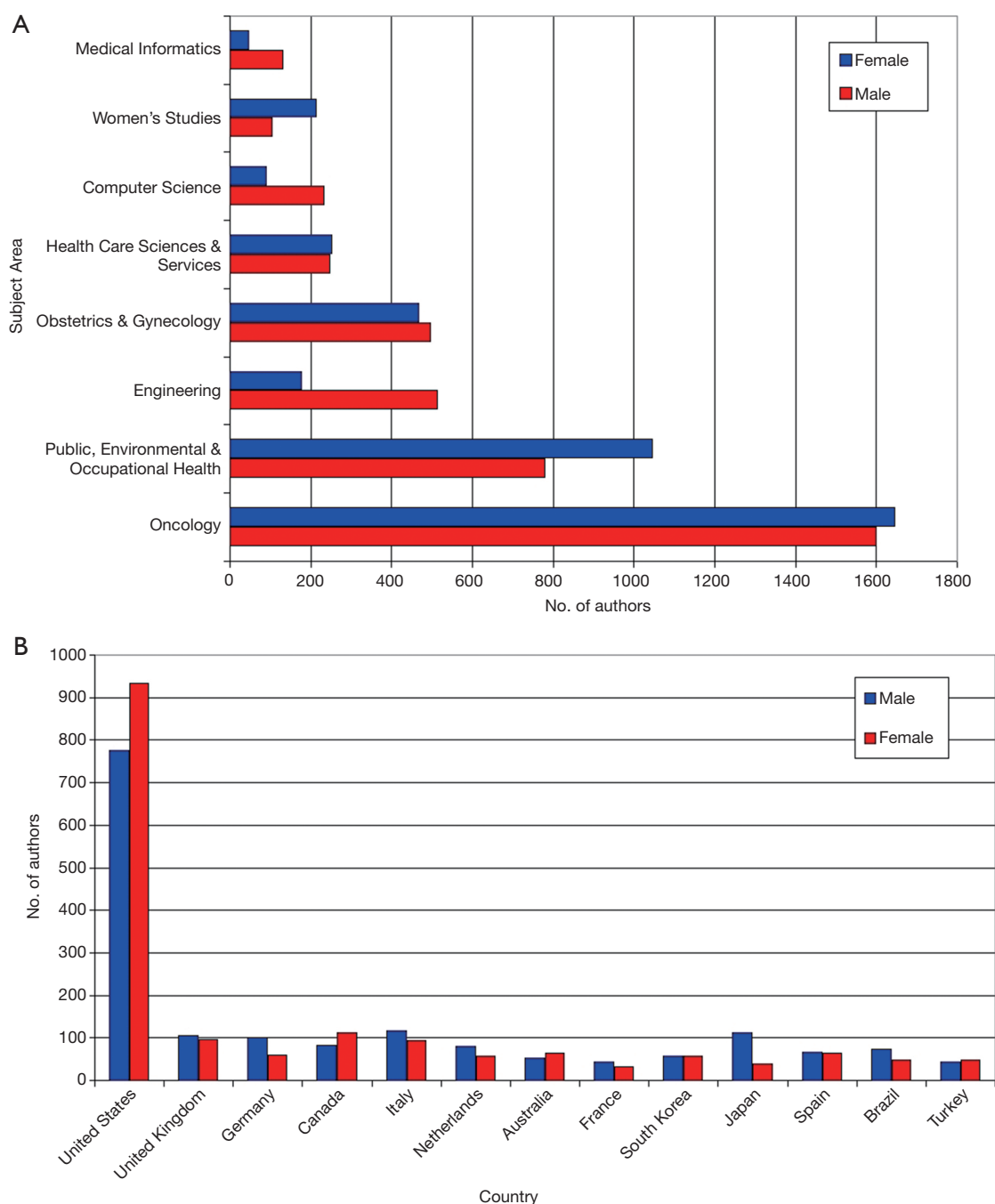

Figure 8 Analysis of the gender of authors publishing on mammography. (A) Subject areas of articles published by authors of a respective gender. (B) Gender of authors analysed by originating country.

publication within the research community than quantify the true scientific quality of the article. Also, another considerable limitation of our method is the difficult reproducibility of our approach since the NewQIS system is a unique computing platform located in our department and

an adaptive system, which is continuously improving for a decade.

As in other fields of science, only low scientific activities were recorded in the field of mammography during the first years after its inception in 1927. After 1960, a first,

very modest increase in annual publication activity was observable. This development can be attributed to key improvements related to its applications and the technique itself (e.g., the vacuum film cassette), which translated into a growing scientific interest. The establishment of mammography as a screening tool was cemented in the 1980s leading to a vast number of scientific activities related to clinical trials afterwards and to annual publication rates of more than 100 articles per year. From 2011 onwards, more than 400 annual articles were identified. When we related the annual publication output to key articles in the field (identified by citation count) we could deduce main topics of interest. 16 articles with more than 500 citations were published from 1985 onwards (*Table 2*). Eight of these reported the findings of large screening trials whereas the remaining were dedicated to topics such as mammographic features and cancer risk prediction, digital techniques or diagnostic accuracy of mammography compared to other screening approaches. These key topics are also reflected in our analysis of main key words (*Figure 6*).

When the publishing institutions were analyzed, it became clear that US-American institutions dominate mammography research. Only limited data is available on the global research patterns related to other diseases and conditions observed in females. Several studies addressed smoking in pregnancy, gestational diabetes and cesarean section, with the US, the UK, Germany and Canada being among the leading countries (39-41). The results of these studies showed a comparable country-specifc publication pattern to our findings for mammography research. This pattern of activity was also reported for breast cancer (16). Here, US-American authors dominated the field with 77,101 breast cancer-related items and 2,389,337 citations (16) followed by their colleagues from the UK. While the total research activities may not be compared due to differences in the study set up (i.e., time period and search criteria), it is obvious that the most active countries are the same in breast cancer and mammography research. However, subject area analysis of single countries provided interesting country-specific insights. In particular, Australia - which is ranked 8th in global mammography research and 9th in global breast cancer research (16)—appeared to be a country with a strong interest in the epidemiologic assessment of the technique. Country-specific differences in global research activities were also analyzed in over five million research publications (42). Within 21 organ systems, a clear dichotomy was identified which was present between Eastern and Western high-income countries (42). In

contrast to the present findings on mammography research, the global research power study found Japan being ranked second (for mammography ranked only 12th), followed by Germany and the UK (42). Even more interesting is our gender analysis concerning Japan: Whereas most countries with a high research activity show more or less a balance between male and female authors, Japan has a male to female ratio of 2.9, clearly indicating a gender imbalance towards male authors, i.e., in contrast to US-American authors with a ratio of 0.83. This finding is not unique to the field of mammography research. It was verified in numerous other areas of science, technology, engineering and mathematics and is linked to specific cultural conventions in Japan (43).

Overall, patterns of country-specific publication activity on "mammography" and "breast cancer" (16,17) were not only similar but also paralleled prevalence rates. Prominent scientific power players were located in North America, Australia, and Europe, where breast cancer is a relevant public health issue. In contrast, African and Asian countries were characterized by minimal contributions but also low incidence rates of breast cancer. Also, South American countries were minimized on the map of mammography research. In these countries, other disease entities are in the focus of national authors. For example, when infectious diseases were analyzed for research output, countries such as Brazil take positions among the top ten countries, as demonstrated for toxoplasmosis (25), or tuberculosis (44). However, we deduce from these findings that countries, whose inhabitants are burdened by breast cancer, actually do research to address this issue. But South-American countries, where breast cancer is a leading cause of cancer death in women, do not particularly focus on mammography-related research. This is a major shortcoming. Furthermore, we also conclude from our subject area analysis that important fields such as public health should be fostered to address breast cancer detection on a broad population scale. When focusing on socioeconomic features, the country-specific mammography research activities can be related to figures such as GDP or population metrics (which can serve as proxies for economic capabilities to invest in research and scientific manpower). In contrast to studies addressing other areas of medicine, we found for mammography that the US retained a very good position—regardless of its highest GDP or its high number of its population in relation to other high-income countries. When other countries with a high population and high total GDPs such as China or India are analyzed, it is evident that

their relative contribution to mammography research is very small in P1, whereas their increasing contribution in P2 was clearly observable.

The debate if and how much women benefit from regular mammography screening is still ongoing as reflected by the numerous diverging guidelines issued by international specialist societies such as the Swiss Medical Board, the American Cancer Society or the US Preventive Services Task Force (45) (46,47). Also, many research questions remain unanswered related to the financial and psychological burden of tumour overdiagnosis or the role of tomosynthesis in breast cancer screening (10). Hence, we call for appropriately powered multisite trials to address the most pressing issues, the establishment of international research collaborations to share resources and include countries with low scientific output as well as an increased funding volume dedicated to mammography research with a special focus on public health (41).

Conclusions

The present study represents the first concise assessment of the worldwide mammography research architecture. We evaluated the related research activity including quantitative (overall research output) and semi-qualitative aspects (citation parameters), socioeconomic features and gender issues. We depict a picture of the global mammography research activity over the last century, which largely follows economic figures and prevalence rates but displays distinct differences in comparison to other biomedical entities.

Acknowledgments

Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/qims-19-774). The authors have no conflicts of interest to declare.

Ethical Statement: Ethical approval and informed consent are not required since this is a non-human study.

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