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ORIGINAL ARTICLE

Status and trends of personalized medicine research from 2000 to 2020: a bibliometric analysis

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ABSTRACT

Background: Personalized medicine (PM), as a rapidly growing research area, provides treatments, practices, and interventions being adapted to an individual patient based on his own risk of disease. This study aims to analyze the productivity of countries, institutions, and authors in this field, to determine the existing research trends worldwide, and to forecast future research activity for specific countries.

Methods: Documents published between 2000 and 2020 were retrieved from the Web of Science (WoS) database. Bibliometric analysis was performed to assess the outputs, correlation analysis was applied to analyze the relationship between Gross Domestic Product per capita (GDP-PP) and the number of publications, and an extrapolation method was used for predicting the future productivity trends for certain countries.

Results: A total of 7,772 documents were published globally on PM between 2000 and 2020. The most productive country, journal, and institution are the USA, *Personalized Medicine*, and Harvard Medical School, respectively. The USA is also first in line in terms of total citations. Netherlands, Denmark, and the USA are listed at the top in terms of the total number of papers and citations, after adjusting for GDP-PP and population size. Also, as predictions suggest, the USA will maintain its predominant role in the PM field in the next 5 years.

Conclusions: Owing to its both interdisciplinary and multidisciplinary nature, PM bestows researchers' numerous sources to benefit and enables them a field that they can be productive of for the future. Therefore, this field is expected to progress and be the lead area in medicine in the upcoming years.

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Personalized medicine; bibliometric analysis; healthcare; prediction; Gross domestic product per capita

Introduction

Personalized Medicine (PM) is defined as a form of medicine that uses information about a person's own genes or proteins to prevent, diagnose, or treat disease[1]. The description of PM was later specified by giving more emphasis to patient-centered care by the European Council Conclusion on Personalized Medicine. Understanding the genetic basis of the disease is important for the development of PM. Recent technical advances in genetics have provided new therapeutic approaches for many diseases, including cardiovascular, neurodegenerative, and cancer[2,3]. Further, the use of individual data allows us to evaluate new strategies of early therapeutic interventions for a specific patient.

Since its first introduction in 1999[4], rapid and notably progress has been observed in the PM field. Its prevailing utilization in clinical branches has been supported by cutting-edge technologies such as transcriptomics, pharmacogenomics, and pharmacokinetics to improve the success of trial designs of antiepileptic drugs in epilepsy[5], clinical utility indexes were developed using PM approaches to personalize the dose selection process based on individual patient preferences[6]. Moreover, PM perspectives were preferred recently in the case of considering personal characteristics in clinical decision-making[7].

Bibliometric analysis is a statistical method for evaluating both the quantity and the quality of the publications in the field of interest[8]. This analysis also demonstrates the research evolution and the changes in the area in question[9]. Also, it detects popular research areas and research trends for the specific area within a specified time interval. In this way, it enables researchers to identify research topics that will require further research[10] and helps find international collaborations more easily. For a decision-making perspective, bibliometric analysis guides policymakers and research managers to utilize it as a reliable resource[11].

Numerous bibliometric analyses have been published in a wide range of areas, including life, natural, and health sciences[12–14]. Moreover, this type of research has gained much attention as a result of remarkable research efforts in medical sciences[10,15], even many bibliometric analyses in various clinical fields with a focus on COVID-19 have their places in

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literature[16,17]. However, to the best of our knowledge, there is only one single study found in the literature that focuses on the research activity of the PM area[18]. On the other hand, few studies have been published in the precision medicine field[19,20]. Considering that the PM field will become more widespread in almost every clinical specialty in the upcoming years, the aim of the study is determined as assessing the current status, international research activity, and future trends of PM over the last two decades, based on the publications between 2000 and 2020.

Methods

The Web of Science Core Collection (WoS) database (www.webofknowlege.com) was used for retrieving the data since it provides peer-reviewed, high-quality academic journals published worldwide. The search was carried out on September 6, 2021, and publications between 2000 and 2020 were retrieved. The search was carried out using the keywords ("personalized medicine") OR ("personalised medicine") in the "topic" selection mode. The search strategy is given below:

TOPIC = ("personalized medicine" or "personalised medicine"), TIME-SPAN = 01/01/2000-12/31/2020

The "personalized medicine" term was first introduced in 1999[4], followed by two other publications that year. However, active research on the PM area began in the early 2000s and papers in this field have been publishing since then. Therefore, the time interval of our study covers the last two decades, namely between 2000 and 2020. The search results were filtered to include publications in English, and article research type. The .txt documents that included full records and cited references were downloaded from the WoS website.

Within the context of the study, some indexes were calculated to show standardized production activity after adjusting for population size and GDP-PP. Formulations are given below:

$$Publication/Population\ Index = \left(\frac{Publication}{Population}\right)*1,000,000$$

$$Publication/GDP-PP\ Index = \left(\frac{Publication}{GDP}\right)*1,000$$

$$TC/Population\ Index = \left(\frac{TC}{Population}\right)*100,000$$

$$TC/GDP-PP\ Index = \left(\frac{TC}{GDP-PP}\right)*100$$

Moreover, the most active authors were evaluated *via* author–impact metrics such as the h-index and g-index. H-index, which is also known as Hirsch Index[21], is defined as the number of papers with a citation number $\geq$ h; while the g-index, which could be seen as an improvement of the h-index[21], is described as the largest number *n* of most cited articles whose mean number of citations is at least n^2. Both indexes are functional to identify the scientific productiveness of a researcher.

Statistical analysis

Biblioshiny interface of the bibliometrix R package (www.bibliometrix.org)[22] and VOSviewer software (v.1.6.16) were used for all the analyses. Frequency (*n*) and percentages (%) were given as basic descriptive statistics for categorical variables, while median and (minimum–maximum) were reported for numerical ones. Kruskal-Wallis test was used for comparing single country publications (SCP) in terms of income classification of countries. Income classifications, as well as GDP-PP values and population size information, were retrieved from https://data.worldbank.org/. Spearman and Pearson correlation coefficients were calculated to analyze the relationship between the number of papers and GDP-PP values of the countries. Furthermore, two different multiple linear regression analyses were performed to investigate factors affecting the number of publications (NP) and the number of total citations (TC). Enter method was used for variable selection to observe the effect of each variable on the dependent variable. Moreover, the number of publications was predicted using the linear extrapolation method and reported with 95% confidence intervals for the top-five most productive countries. Citation analysis, co-occurrence analysis, co-authorship analysis, and corresponding graphics were obtained by VOSviewer, while biblioshiny application of bibliometrix package were applied for the remaining analyses.

Results

The total number of publications on personalized medicine between 2000 and 2020 years was 7,772. The distribution of publications over the last 20 years and average total citations of publications per year are depicted in Figure 1. The annual growth rate was 36.16%, indicating the number of publications was in an increasing trend. The peak was in 2020, with 959 publications in terms of annual scientific production, while the peak year was in 2012, with 5.57 average citations per year. Besides, a total of 37,464 authors contributed to this area, with 0.206 article/author, 4.86 authors/article, 6.83 co-authors/article, and a collaboration index of 5.24. Median and minimum–maximum values for single country publications (SCP), multi-country publications (MCP), and the total NP were calculated as 6 $(0-2{,}324)$, 3 $(0-514)$, and 10 $(1-2{,}838)$, respectively. Also, median, minimum, and maximum values of NP for high-income, upper-middle-income, lower-middle-income, and low-income countries were found as, 44 $(2-2{,}838)$, 5.5 $(1-590)$, 2 $(1-105)$, and 1 $(1-1)$ respectively ($p < .001$). Furthermore, Total Citation (TC) counts for high, upper-middle, lower-middle, and low-income countries were calculated as 584 $(4-86{,}994)$, 26 $(4-11{,}900)$, 13 $(0-1{,}264)$, and 3 $(1-11)$, respectively ($p < .001$).

Most active countries regarding publications on personalized medicine are listed in Table 1. The USA ranked first, followed by China and Italy in terms of SCP; while the USA, UK, and China formed the first three countries, respectively, in

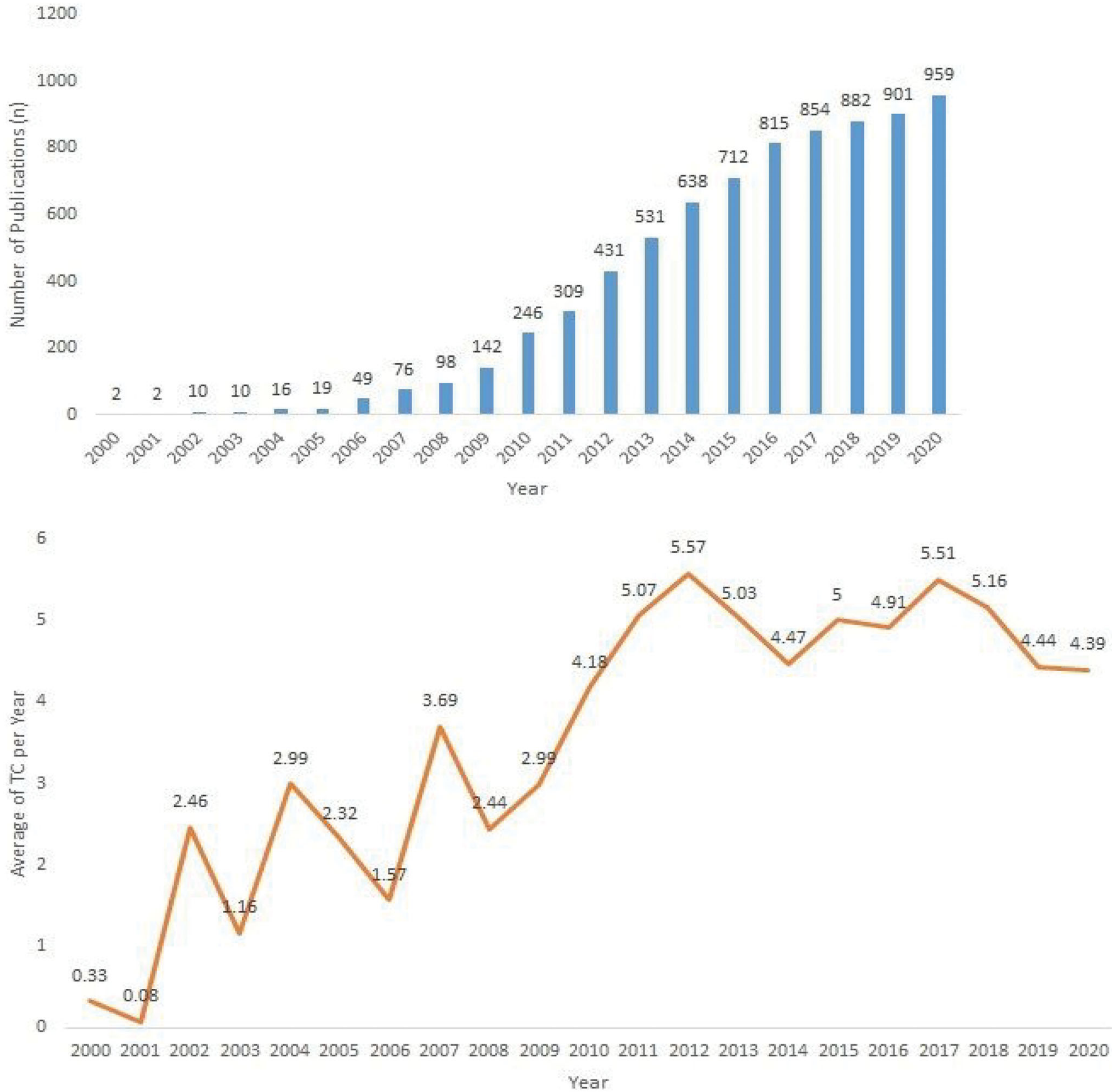

Figure 1. The number of publications and average of total citations (TC) on PM between 2000 and 2020.

MCP categories. In total, however, the USA, China, and the UK were placed as the top three. Furthermore, Korea, Japan, and the USA ranked first, second, and third in terms of SCP proportion, whilst Switzerland was first in line in MCP proportion, followed by Belgium and Netherlands. Proportion results revealed that Switzerland was the only country whose MCP proportion was higher than the proportion of SCP, making this country the most productive one in international collaboration. In terms of total citations, the USA ($n = 86{,}994$), UK ($n = 18{,}682$), and Canada ($n = 11{,}900$) were in the top three, whereas the UK (41.06), Israel (40.84), and Denmark (34.65) were in the lead in terms of average article citations (AAC) (Table 1).

Although the USA ranked first in terms of the total number of publications and citations; Netherlands, Switzerland, and Denmark were placed as the top three in terms of the number of publications; while Denmark, Netherlands, and Israel were listed as the top three in terms of the number of total citations after adjusting for the population size. On the other hand, the USA, China, and India ranked first, second, and third in terms of the number of publications, whereas the USA, China, and the UK were the top three in terms of total citations after adjusting for GDP (Table 2).

Personalized medicine publications were categorized into 180 study types in terms of the Web of Science (WoS) category. The top five category can be listed as Pharmacology Pharmacy ($n = 1{,}116$, 14.36%), Oncology ($n = 960$, 12.35%), Genetics Heredity ($n = 680$, 8.50%), Medicine Research Experimental ($n = 533$, 6.86%), and Multidisciplinary Sciences ($n = 428$, 5.51%). A total of 2,177 journals published papers regarding personalized medicine. *Personalized Medicine* published 202 articles as the leading journal of this research

Table 1. The most productive and the most cited countries in terms of personalized medicine research.

Country	Articles	SCP (%)	MCP (%)	Country	TC	Country	AAC
USA	2,838	2,324 (82)	514 (18)	USA	86,994	UK	41.06
China	590	432 (73)	158 (27)	UK	18,682	Israel	40.84
Italy	436	319 (73)	117 (27)	China	11,900	Denmark	34.65
Germany	425	278 (65)	147 (35)	Germany	7,977	Singapore	31.80
UK	455	275 (60)	180 (40)	Netherlands	7,221	USA	30.65
Canada	336	225 (67)	111 (33)	Italy	6,820	Malta	30.50
Netherlands	290	167 (58)	123 (42)	Canada	6,387	Belgium	28.41
France	230	154 (67)	76 (33)	France	5,824	Japan	25.88
Spain	206	141 (68)	65 (32)	Australia	4,205	Korea	25.36
Japan	145	122 (84)	23 (16)	Japan	3,752	France	25.32
Australia	180	113 (63)	67 (37)	Israel	3,471	Netherlands	24.90
Korea	107	91 (85)	16 (15)	Spain	3,266	Switzerland	23.71
India	105	80 (76)	25 (24)	Korea	2,713	Australia	23.36
Israel	85	58 (68)	27 (32)	Switzerland	2,679	Finland	22.74
Switzerland	113	51 (45)	62 (55)	Denmark	2,564	China	20.17
Sweden	80	49 (61)	31 (39)	Belgium	2,443	New Zealand	20.17
Belgium	86	46 (53)	40 (47)	Sweden	1,613	Sweden	20.16
Denmark	74	44 (59)	30 (41)	Singapore	1,590	Mexico	19.33
Russia	56	41 (73)	15 (27)	India	1,264	Austria	19.07
Singapore	50	32 (64)	18 (36)	Austria	1,125	Canada	19.01

Abbreviations. SCP, Single Country Publications; MCP, Multiple Country Publications; TC, Total Citations; AAC, Average Article Citations.

Table 2. Publication/population index, publication/GDP index, TC/population index, and TC/GDP index for top countries on personalized medicine research.[b]

Country	Publication/Population Index[a]	Country	Publication/GDP Index[a]	Country	TC/Population Index[a]	Country	TC/GDP Index[a]
Netherlands	16.6	USA	44.7	Denmark	43.9	USA	136.9
Switzerland	13.1	China	34.1	Netherlands	41.4	China	68.7
Denmark	12.7	India	16.3	Israel	37.6	UK	41.6
Luxembourg	12.6	Italy	10.4	Switzerland	31.0	India	19.6
Ireland	10.6	UK	10.1	Singapore	27.9	Italy	16.3
Israel	9.2	Germany	7.9	UK	27.8	Germany	14.8
Canada	8.8	Canada	7.0	USA	26.4	Canada	13.3
Singapore	8.8	Spain	5.4	Luxembourg	24.0	France	12.6
USA	8.6	France	5.0	Belgium	21.1	Netherlands	12.2
Finland	8.3	Netherlands	4.9	Finland	18.9	Japan	8.9
Sweden	7.7	Japan	3.4	Ireland	17.0	Spain	8.5
Belgium	7.4	Australia	3.4	Canada	16.8	Israel	8.3
Italy	7.3	Korea	2.5	Australia	16.4	Australia	8.0
Australia	7.0	Brazil	2.4	Sweden	15.6	Korea	6.3
UK	6.8	Iran	2.3	Austria	12.6	Belgium	4.7
Austria	6.6	Israel	2.0	Italy	11.4	Denmark	4.2
Cyprus	5.8	Russia	2.0	Germany	9.6	Switzerland	3.7
Slovenia	5.7	Greece	1.9	France	8.6	Sweden	2.9
Greece	5.1	Pakistan	1.8	New Zealand	7.1	Brazil	2.5
Germany	5.1	Belgium	1.6	Spain	6.9	Greece	2.4

[a]Indexes were calculated as follows: Publication/Population Index = (Publication/Population)*1,000,000; Publication/GDP Index = (Publication/GDP-PP)*1,000; TC/Population Index = (TC/Population)*100,000; TC/GDP Index = (TC/GDP-PP)*100.
[b]The cut-off value of NP was taken as five. Countries whose total number of publications are higher than five were analyzed.
Abbreviations. GDP, Gross Domestic Product per capita; TC, Total Citations.

area, followed by *PLoS One* ($n = 172$) and *Pharmacogenomics* ($n = 127$). On the other hand, *New England Medical Journal* was observed as the most cited source, with 8,192 publications, followed by *Nature* with 7,107 publications, and the *Journal of Clinical Oncology* with 6,042 publications. Table 3 briefly demonstrates the journals' metrics.

Literature on personalized medicine was published by 6,945 different institutions during the study period. Harvard Medical School was the lead contributor to personalized medicine research, with 381 publications, followed by the University of California (355 publications) and INSERM (216 publications). In terms of funding agent ranking, the United States Department of Human Health Services (1,719 publications), National Institutes of Health (NIH) (1,709 publications), National Cancer Institute (NCI) (578 publications), European Commission (548 publications), and National Natural Science Foundation of China (NSFC) (359 publications) form the top five list on research grants.

Most productively active authors in this research field are given in Table 4, along with authors' metrics such as the total number of citations (TC), h-index, and g-index, and their affiliations. Results in Table 4 depicted that Mccarty CA was first in line in terms of both h-index (h-index = 18) and g-index (g-index = 30) and Swanton C was first in terms of the number of total citations (5,391 citations). It should be mentioned that the h-index values reported in Table 4 do not reflect the total h-index metric of the authors, the values were calculated based on the citations of PM-related papers. The authors' metrics are given in Table 4.

Table 3. The most active journals and the most cited journals in terms of personalized medicine research.

Source	NP	5-Year IF	Sources	NC	5-Year IF
Personalized Medicine	202	2.201	*New England Journal of Medicine*	8,192	89.676
PLoS One	172	3.788	*Nature*	7,107	54.637
Pharmacogenomics	127	2.587	*Journal of Clinical Oncology*	6,042	33.883
EPMA Journal	94	6.064	*Proceedings of the National Academy of Sciences (USA)*	4,854	12.291
Scientific Reports	70	5.134	*PLoS One*	4,396	3.788
Oncotarget	66		*Science*	4,307	51.434
Proceedings of the National Academy of Sciences (USA)	66	12.291	*Clinical Cancer Research*	3,574	12.836
OMICS – A Journal of Integrative Biology	61	3.112	*Clinical Pharmacology & Therapeutics*	3,443	7.226
Clinical Pharmacology & Therapeutics	53	7.226	*Cancer Research*	3,316	12.843
Public Health Genomics	47	2.296	*Lancet*	2,959	77.237
Clinical Cancer Research	46	12.836	*JAMA –Journal of the American Medical Association*	2,859	60.151
International Journal of Pharmaceutics	44	5.423	*Nature Genetics*	2,817	36.431
Journal of the American Medical Informatics Association	38	5.178	*Nucleic Acids Research*	2,638	15.542
BMC Cancer	36	4.372	*Cell*	2,450	46.899
Statistics in Medicine	36	3.267	*Genetics in Medicine*	2,051	12.372
International Journal of Molecular Sciences	35	6.132	*Bioinformatics*	2,012	8.470
Genetics in Medicine	33	12.372	*Blood*	2,006	20.107
Journal of Personalized Medicine	32	4.994	*Journal of Biological Chemistry*	1,762	5.041
Bioinformatics	29	8.470	*Pharmacogenomics*	1,761	2.587
BMC Bioinformatics	29	3.629	*Nature Biotechnology*	1,640	50.516

Abbreviations. NP, Number of Publications; NC, Number of Citations; IF, Impact Factor.

Table 4. The most active authors on PM research in terms of total citations and h-index and g-index metrics.

Author	h-index	Affiliation	Author	g-index	Affiliation	Author	TC	Affiliation
McCarty, C. A.	18	University of Minnesota System	McCarty, C. A.	30	University of Minnesota System	Swanton, C.	5,391	University College London
Denny, J. C.	17	Vanderbilt University	Roden, D. M.	27	Vanderbilt University	Gerlinger, M.	5,277	Institute of Cancer Research – UK
Roden, D. M.	16	Vanderbilt University	Phillips, K. A.	24	University of California San Francisco	Futreal, P. A.	5,221	UTMD Anderson Cancer Center
Johnson, J. A.	16	University of Chicago	Denny, J. C.	22	Vanderbilt University	Larkin, J.	5,130	Royal Marsden NHS Foundation Trust
Williams, M. S.	15	University of Oxford	Williams, M. S.	22	University of Oxford	Martinez, P.	5,119	Universite Claude Bernard Lyon
Peterson, J. F.	14	Vanderbilt University	Patrinos, G. P.	22	University of Patras	Rowan, A. J.	5,119	Cancer Research UK London Research Institute
Wilke, R. A.	14	University of South Dakota	Wang, W.	19	Capital Medical University	Szallasi, Z.	5,119	Boston Children's Hospital
Golubnitschaja, O.	13	University of Bonn	Johnson, J. A.	18	University of Chicago	Gore, M.	5,057	Royal Marsden NHS Foundation Trust
Green, R. C.	11	Brigham & Women's Hospital	Llerena, A.	17	Universidad de Extremadura	Pickering, L.	5,057	St Georges Univ Hosp Fdn Trust
Ingelman-Sundberg, M.	11	Karolinska Institutet	Peterson, J. F.	16	Vanderbilt University	Santos, C. R.	5,057	Cancer Research UK London Research Institute

h-index is based on researcher's most cited papers and the number of citations that they have received in other publications, g-index is calculated based on the distribution of citations received by a given researcher's publications.
Abbreviation. TC, Total Citations.

Within the context of this current study, multiple linear regression analysis was performed for determining factors associated with the total number of publications (NP) and total citations (TC). Results revealed that standardized population levels and TC counts were significant factors for NP; while TC counts were observed to be affected by NP and standardized population levels. Interesting to mention that neither income levels of countries nor GDP-PP values were found to influence both NP and TC counts (Table 5).

Co-occurrence network analysis based on the author's keywords, co-authorship analysis based on countries, and citation analysis based on sources are illustrated in Figure 2. Co-occurrence analysis showed that 15,228 keywords were utilized in PM studies. The minimum number of occurrences of a keyword was set as five, and this criterion revealed 857 keywords that met the threshold. The indicator in the figure of co-occurrence analysis indicates current documents from dark blue to yellow (Figure 2a). Similarly, the indicator in the figure of citation analysis showed the current number of average citations from dark blue to yellow (Figure 2b). Co-authorship analysis revealed that there are 10 clusters based on worldwide collaboration (Figure 2c).

Gross Domestic Product (GDP) is described as the total value of goods produced and services provided in a country during 1 year. GDP per capita is gross domestic product divided by midyear population. In that aspect, correlation analysis results for the top-five countries showed that all five countries have a very strong correlation with its NP and its GDP per capita. The correlation coefficients were found as $r = .954$ ($p < .001$) for the USA, $r = .975$ ($p < .001$) for China, $r = .966$ ($p < .001$) for Germany, and $r = .978$ ($p < .001$), $r = .913$ ($p < .001$) for the UK and Italy, respectively.

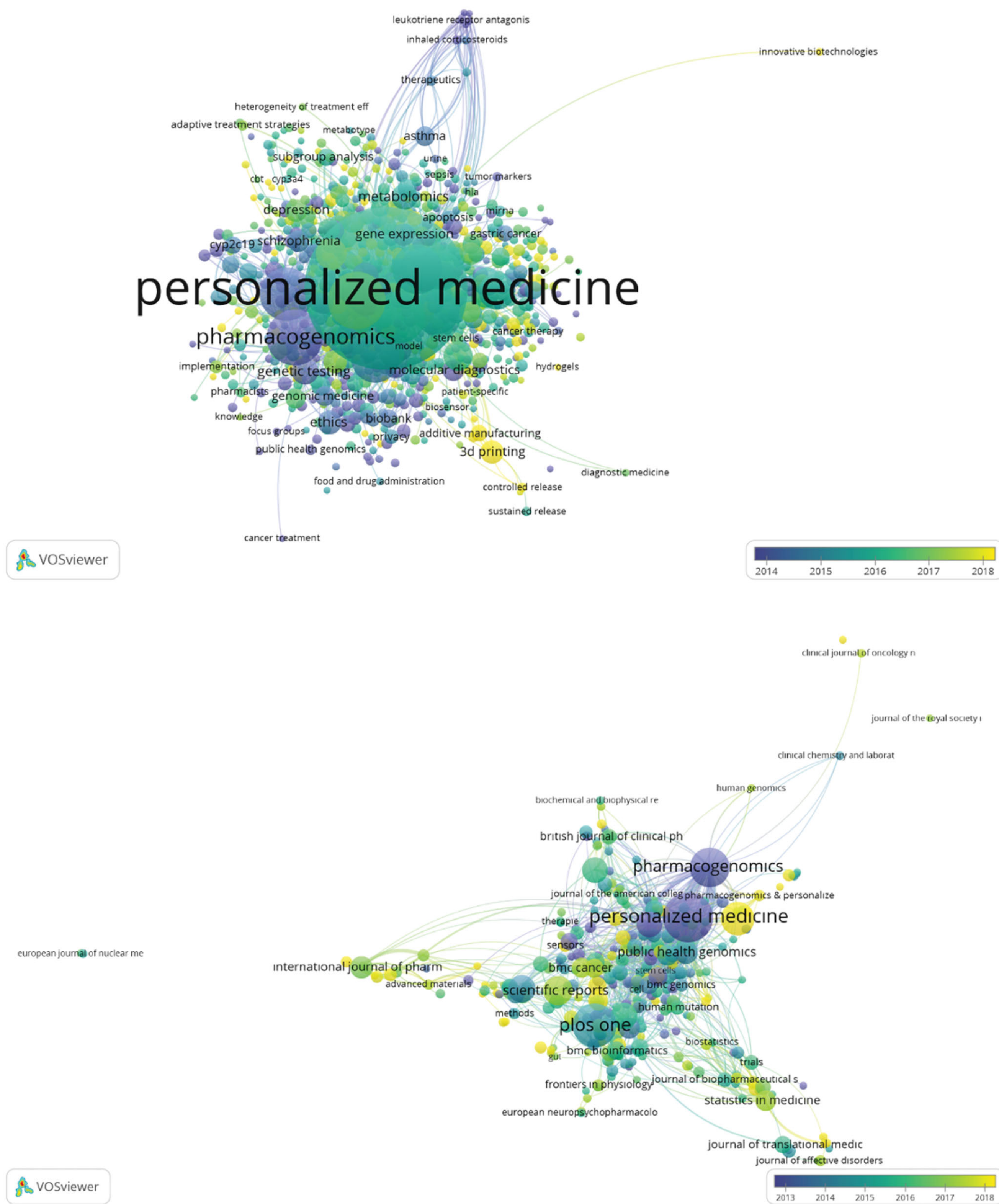

Figure 2. (a) Co-occurrence analysis. (b) Citation analysis. (c) Co-authorship analysis. Cluster 1 (red): Austria, Belgium, Bulgaria, Colombia, Cyprus, Czech Republic, France, Germany, Hungary, Lithuania, Malta, Poland, Qatar, Romania, Serbia, Slovakia, Slovenia, Switzerland, Ukraine. Cluster 2 (green): Australia, Canada, Greece, India, Iran, Malaysia, New Zealand, Nigeria, South Africa, South Korea, Thailand, UAE. Cluster 3 (blue): Denmark, Estonia, Finland, Norway, China, Singapore, Sweden, Taiwan, USA, Vietnam. Cluster 4 (light green): Argentina, Brazil, Chile, Croatia, Italy, Jordan, Mexico, Spain. Cluster 5 (purple): Bosnia, England, Ireland, Northern Ireland, Pakistan, Scotland, Turkey, Wales. Cluster 6 (light blue): Egypt, Ghana, Portugal, Saudi Arabia. Cluster 7 (orange): Indonesia, Japan, Netherlands. Cluster 8 (brown): Lebanon, Luxembourg, Russia. Cluster 9 (pink): Iceland, Israel.

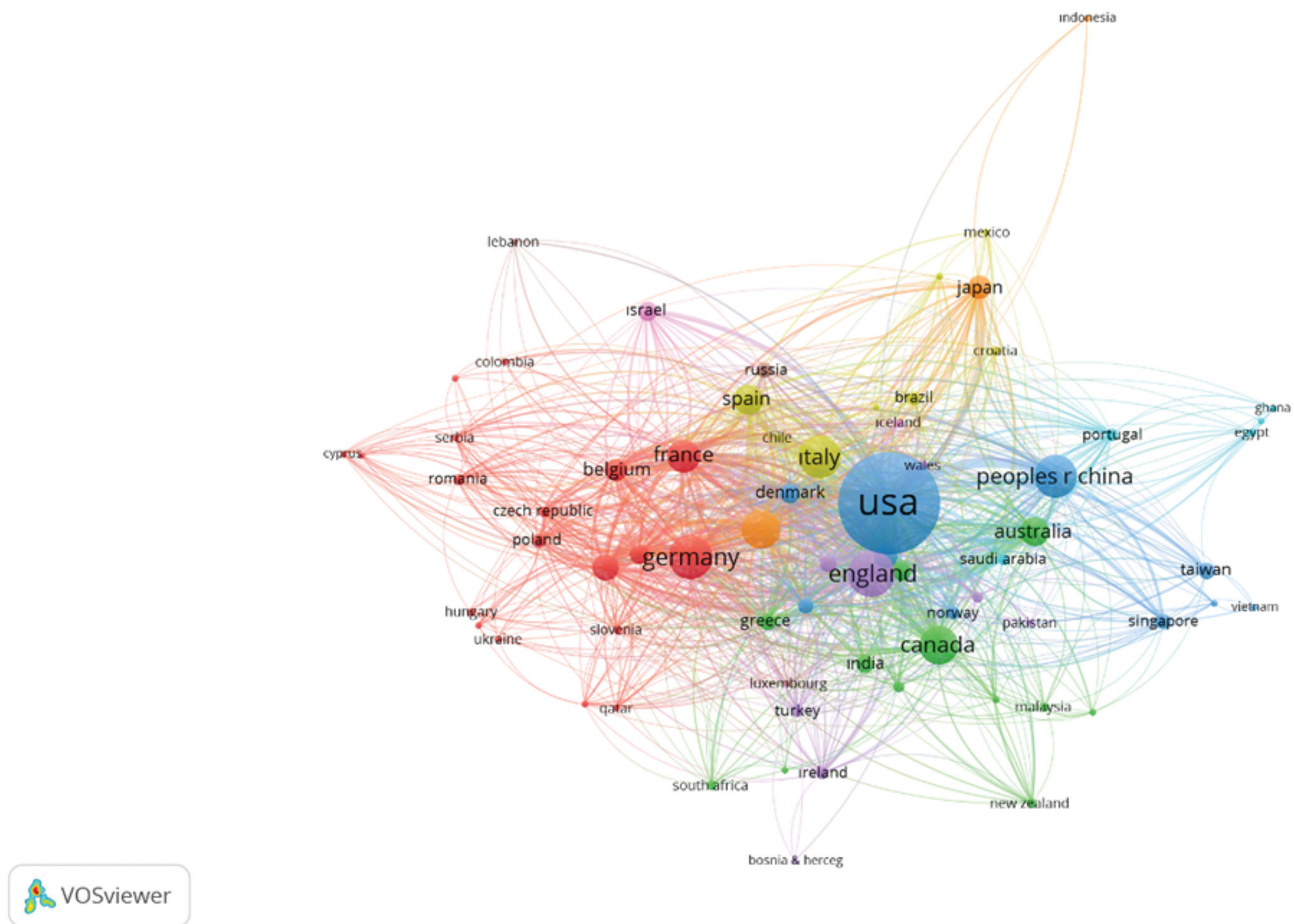

Figure 2. Continued.

Table 5. Results of multiple linear regression analysis.

Dependent Variable	Independent Variables	β	SE(β)	p value	95% CI for β	
					Lower	Upper
TC	NP	30.827	.589	<.001	29.64	32.013
	Population (STD)	−844.843	254.307	.002	−1,356.74	−332.949
	Constant	−1,072.755	329.008	.002	−1,735.01	−410.495
	$F = 627.089$, $p < .001$; R^2-adj = 98.4%					
NP	TC	0.032	.001	<.001	.031	.033
	Population (STD)	29.616	7.995	.001	13.523	45.709
	Constant	37.658	10.348	<.001	16.828	58.488
	$F = 655.218$, $p < .001$; R^2-adj = 98.5%					

The correlation between TC and NP was found to be .966 ($p < .001$), indicating a strong positive association between these two components as expected. Similar strong associations were also observed for different income levels. That is, correlation analysis results for TC and NP for lower-middle, upper-middle-, and high-income countries were .876 ($p < .001$), .960 ($p < .001$), and .983 ($p < .001$), respectively.

The number of publications for the next 5 years was predicted for the most active five countries. Results have shown that the number of documents per year of the USA, China, and the UK were expected to sharply increase, and by 2025 they were expected to produce 448, 158, and 124 publications, respectively. The same increasing patterns were also observed for the remaining countries, namely Germany and Italy. But their trend was not as sharp as the aforementioned countries. By the year 2025, 164 (Germany) and 161 (Italy) SCP were expected to be produced by these countries. Results of this extrapolation analysis have demonstrated that the same active pattern will be observed for the upcoming 5 years in the PM area, and the USA will maintain its predominant role in this field (Figure 3).

Discussion

Results for this present study revealed that the USA is in the lead in terms of the total number of publications and total citations. However, Netherlands and Denmark were found to

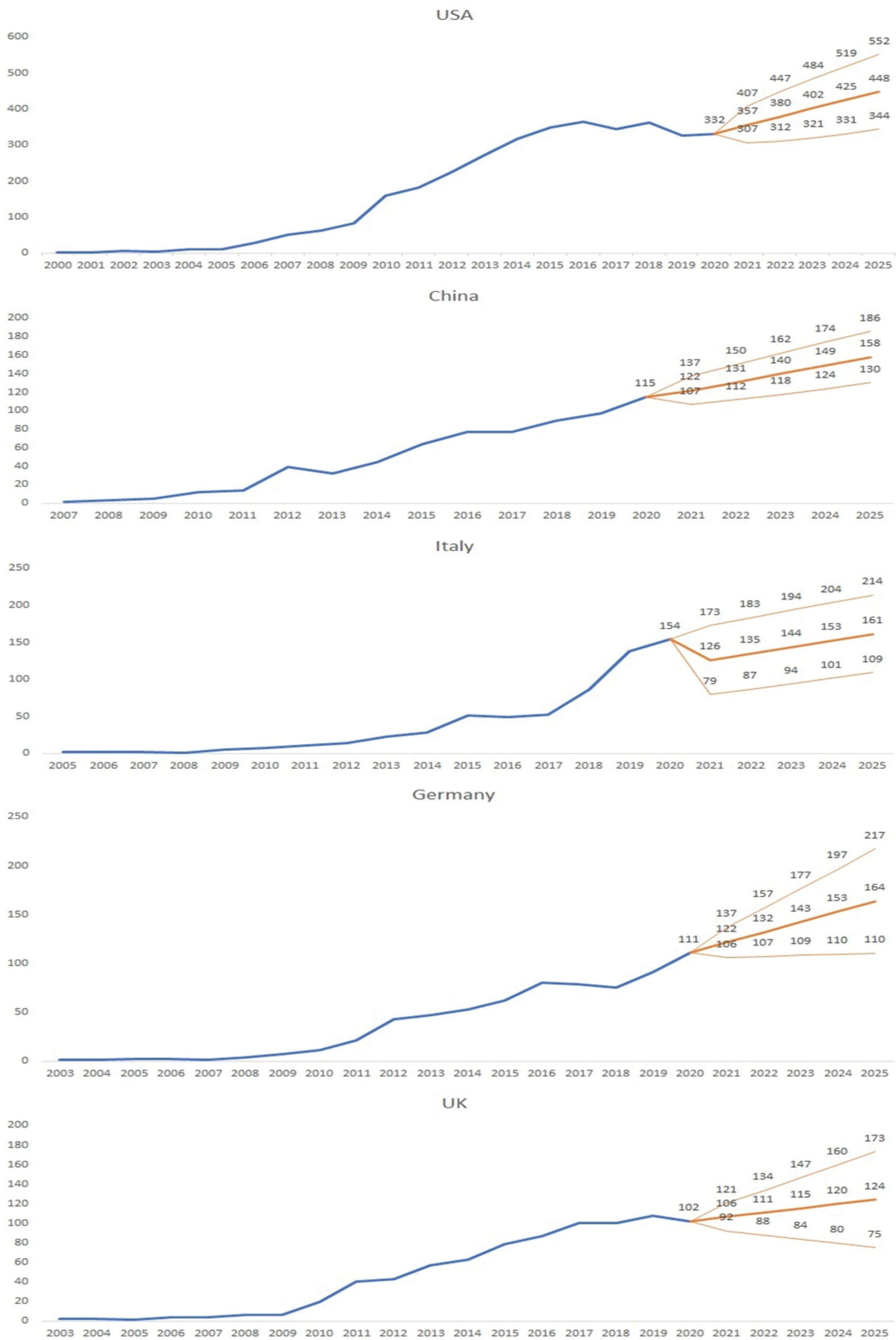

Figure 3. Predicted number of publications for the USA, China, Italy, Germany, and the UK for the next 5 years.

be in the top three in terms of the total number of papers and the total number of citations after adjusting for population size. Thus, overall, Netherlands and the USA can be defined as the lead countries in the PM field. However, the USA is expected to be in the front-line for the upcoming 5 years, as predictions suggest. Harvard University was found to be the most active research institution in this field. Much of the work has been done in the pharmacology pharmacy field, *Personalized Medicine* journal was the lead journal in terms of 202 papers published within the study period, while the *New England Medical Journal* was leading in terms of citations.

Even though there are numerous bibliometric analyses in the literature related to medical research, to the best of our knowledge, there is only one single bibliometric study about the PM field[18]. Romagnuolo et al[18] evaluated the current status of the collaborations between the European Union (EU) and China in the PM area and stressed the importance of policymakers in promoting cooperation between researchers, innovators, industries, regulators, funding agencies, and healthcare systems. Similarly, China was listed among the top in terms of publication activity. In contrast, the present study's focus is on assessing PM's current status and future trends worldwide based on publications of the last two decades. Various numerical results obtained from different statistical methods and forecast results for future trends were reported in this regard. On the other hand, some documents have been published regarding the precision medicine field, which is similar to PM but differs in treatment methods and target samples. Le Texier et al.[19] have published a bibliometric analysis on precision medicine with a focus on oncology and emphasized the importance of international collaboration as well as data sharing in this area. Moreover, similar to our results they have reported USA and UK as the key contributors to precision medicine research activity[19]. In their review, Williams et al.[20] have stressed the wide application areas across different clinics, and pointed out the importance of singular precision medicine definition to provide a common understanding of the concept, with the help of the documents from 2012 through November 2018.

Results revealed that lower productivity was observed for countries between 2000 and 2009 compared to the 2010–2020 time span. Since the PM term was introduced in 1999, as an emerging area, the very first publications in this field were being published from the early 2000s at best. Predictably, the lower productivity of the first years could be the result of this circumstance. Another reason might be due in part to the global economic crisis between 2007 and 2009. Decreasing level of research funds during this crisis time might drop the capacity in this area. Besides, fewer researchers in the PM domain in certain countries or regions could hamper the productiveness.

In addition, it's noteworthy to mention that there are disparities between continents, even regions in terms of productivity in the PM area. Results suggested that countries with a high GDP-PP were found to be main contributors to the productivity of this field. Additionally, legislative and ethical differences in different regions could play a role in this imbalance. Therefore, the disparity may mainly be ascribed to a lack of research funds and a low level number of researchers as the result of low GDP-PP. Balance in the productivity could be provided by fostering international collaboration and cooperation worldwide, as well as increasing the research grants and facilitating the transnational partnership to exchange information, practice, and material with a benefit for region productivity.

Two main limitations of this current research are inherited to the study design, namely the usage of only one database, i.e., WoS and recruiting only English-written research papers. Although WoS does not cover the largest number of journals compared to, i.e., Scopus, it is assumed that sufficient high-quality publications, especially in medicine and health sciences, could be analyzed *via* this database. Moreover, all the combinations purposive of this research were examined *via* the WoS database and suitably presented. Additionally, due to the study period (2000–2020), exclusion of the oldest three articles in the PM field, which were published in 1999, could be listed as another limitation. Even though the oldest research articles were ruled out since they are out of scope, it is thought that their absence would not have made a remarkable impact on our findings. Moreover, these limitations might have slight influence on the overall results but are beyond belief to change the main trends depicted in this study.

To the best of our knowledge, this is the first bibliometric study on PM with the detailed statistical analysis, including linear extrapolation to predict the future trend for PM papers, correlation analysis to determine the relationship between GDP-PP and the number of publications for certain countries, and binary logistic regression analysis to investigate factors related to the total number of publications and citations. Furthermore, this present study comprehends a wider time interval compared to other bibliometric analyses with a focus on PM. As such, this broader time interval enables a detailed evaluation of the progression in this field.

Conclusion

Owing to its interdisciplinary and multidisciplinary nature, PM is expected to gain more popularity in the next years. Growing global collaboration and cooperation, as well as increasing trends of research grants will foster researchers to maintain their studies in the PM field. Promoting cross-border collaboration is needed to disseminate PM methodology in clinical guidance. Further, defining common guidelines for PM implementations will help this dissemination. As a result, PM will be expected to be widely used in each clinical specialty soon. Therefore, due to its context, this current research could also be assessed as a guide for both ongoing and upcoming researches in PM field.

Transparency

Declaration of funding

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Declaration of financial/other relationships

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties. Peer reviewers on this manuscript have no relevant financial or other relationships to disclose.

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Data availability statement

Availability of data and materials: data is available upon request.

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