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Availability of digital object identifiers in publications archived by PubMed

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Abstract Digital object identifiers (DOIs) were launched in 1997 to facilitate the long-term access and identification of objects in digital environments. The objective of the present investigation is to assess the DOI availability of articles in biomedical journals indexed in the PubMed database and to complete this investigation with a geographical analysis of journals by the country of publisher. Articles were randomly selected from PubMed using their PubMed identifier and were downloaded from and processed through developed Hypertext Preprocessor language scripts. The first part of the analysis focuses on the period 1966–2015 (50 years). Of the 496,665 articles studied over this period, 201,055 have DOIs (40.48%). Results showed that the percentage of articles with DOIs began to increase for articles published in the 2000s, with spectacular growth in the years 2002–2003, then reached a peak in 2015. Data on countries showed that some countries gradually implemented DOIs over the period 1966 to 2015 (the United States, the United Kingdom, and the Netherlands), while some did not (Russia, the Czech Republic, and Romania). The second part of the analysis focuses on the year 2015 and includes 268,790 articles published in 2015, randomly selected to evaluate the current implementation of DOIs. In 2015, 86.42% of articles had DOIs. The geographical analysis of countries of publishers showed that some countries (Russia, Thailand, and Ukraine) still assigned few DOIs to articles in 2015. Thus, if the scientific community aims to increase the number and the usefulness of services rendered by DOIs, efforts must be made to generalize their use by all persons involved in scientific publication, particularly publishers.

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Introduction

In the last few decades, access to scientific information has almost entirely migrated to a digital environment. This changing environment requires persistent and reliable unique identifiers to manage access to digital resources. The most common identifier on the web is the Uniform Resource Locator (URL), which provides the location of resources. URLs have many limitations. They work properly only if the resources are not removed, and do not provide a means of associating meta information (e.g. file format) about the resource which could help to identify intellectual property rights (Carnevale and Aronsky 2007; Ducut et al. 2008; Park et al. 2011; Wagner et al. 2009). In biology and medicine, the PubMed Identifier (PMID) has long been operating to identify and access articles via the PubMed database. However, the scope of PMID is limited because it only includes journals indexed in PubMed in the field of biology and medicine and is functional only in this database. The lack of similar systems in other scientific fields, and therefore the lack of normalization, resulted in the establishment of the Digital Object Identifier (DOI) in 1997 (Paskin 1999). This system, managed by the International DOI Foundation (IDF) (Chandrakar 2006; "Digital Object Identifier System Handbook" 2016; Paskin 1999, 2010; Simmonds 1999) is now an ISO standard ("ISO 26324:2012—Information and documentation—Digital object identifier system" 2012) and has been identified as one of the best choices among those complying with the definition of a digital identifier from a comparative evaluation based on seven criteria (Khedmatgozar and Alipour-Hafezi 2015).

A DOI name consists of two parts (Sidman and Davidson 2001; Simmonds 1999). The first part consists of a prefix corresponding to a unique numeric string beginning with the numeral 10 assigned by the International DOI Foundation or by DOI registration agencies (e.g. CrossRef for scientific publishers) to the registrant that submitted the information about the digital object (publishers in the case of scientific publications). The second part consists of a suffix corresponding to an alphanumeric string or series of strings assigned by the publisher and is used internally to identify the digital object.

The system operates in such a way that when a DOI is first assigned to an object, the publisher registers its identity and current network location in the DOI system. Incoming requests for the DOI are resolved to the appropriate URL. When the object moves, the publisher of that contents simply updates its DOI record with the new URL. Hence, accessing digital objects using DOIs ensures seamless and correct routing to the new and correct location of objects (Sidman and Davidson 2001) and enables permanent and unambiguous identification and access to digital objects. One of the main benefits of referencing an object by a DOI versus a simple URL is persistence. When an object moves, its URL changes but its DOI remains the same. Furthermore, using DOIs instead of URLs allows multiple resolution. In addition to the DOI and URL, deposited metadata may describe multiple formats of an article (pdf, html, XML) and several locations (e.g. publisher's website, PubMed Central). Therefore, end users can choose their preferred format or download location (DeRisi et al. 2003). The DOI can also be applied at any level of granularity (to a whole book or to chapters, illustrations or tables) or any file type (text, image, audio–video) (Wang 2007).

With the establishment of DataCite in 2009, whose aims are to facilitate access to research data, to increase the acceptance of data publication, and to support data archiving (Brase et al. 2015; Honor et al. 2016; Neumann and Brase 2014), DOIs can also be assigned to research data. During the five past years, DataCite has grown into a global consortium and has assigned over four million DOIs to scientific datasets (Brase et al. 2015).

DOIs offer other advantages for all those involved in the scientific community.

For publishers, paying one annual fee allows access to articles via DOI links and functions even if content moves or changes ownership. DOIs also protect the copyright of published material (Rosenblatt 1997). The adoption of DOIs by publishers increases the discoverability of resources by search engines, increasing the traffic on websites: the number of site views for documents with a DOI were higher by an average of 66% using CrossRef compared to documents without the DOI service (Sieck 2003). Consequently, publishers increase their revenue. For example, for a medium-sized book publisher, the return on investment using the DOI could be as much as 12 times the cost of DOI implementation (Sieck 2003).

For libraries, DOI links can extend access to content not owned by the library and increase usage of acquired electronic resources for end-users at no charge (Wang 2007).

For researchers, DOIs provide access to over 19 million scientific objects available from over 20,000 journals and from over 1500 publishers and companies ("crossref.org" 2016) by simply using a copy/paste of the DOI in a DOI resolver (e.g. https://dx.doi.org/) or using bibliographic tools such as Zotero ("Zotero|Home" 2016). Use of DOIs enriches end-user activity and the scholarly research process, and also guarantees persistent access and citability of articles.

For research funders, now that most of them require researchers to make their articles available in open access with different specifications (licenses and embargo periods), they need to track output from hundreds or even thousands of publishers. Thus, DOIs can offer a reliable way to help these institutions with their compliance processes ("Crossref initiatives will support reporting to funders|Research Information" 2016).

DOIs can also be used in scientific production evaluation. For example, the National Council for Scientific and Technological Development (CNPq) in Brazil signed an agreement with ISI Thomson Reuters to allow access and online viewing of the number of citations in the Web of Science database for the articles registered in the Curriculum Lattes (a virtual platform integrating curricula databases, research groups, and institutions) with their respective DOIs (Braile 2011).

Altmetrics are social web metrics for academic publications incorporating a number of variables such as view count, downloads, and comments in order to measure the impact of articles (Galligan and Dyas-Correia 2013; González-Valiente et al. 2016; Rasmussen and Andersen 2013; Sud and Thelwall 2013). The DOI is an essential element for most sites or tools using altmetrics (Galligan and Dyas-Correia 2013). For example, altmetric.com ("Altmetric" 2016), in order to disambiguate mentions of articles, searching for identifiers such as DOIs in web pages, PLOS Article-Level Metrics ("ALM" 2016) or PlumX ("Plumx" 2015) can create reports from one DOI or from a list of DOIs. Furthermore, following the success of a DOI event tracker ("CrossRef's DOI Event Tracker Pilot—Crossref Blog" 2015; Tolwinska 2015), CrossRef will launch, in early 2017, the service CrossRef Event Data ("Crossref Event Data" 2016), which is an open data service based on DOIs. It will track activity surrounding a research work from potentially any web source where an event is associated with a DOI. This service will help researchers to follow the activity surrounding their articles or research data. Publishers will able to use the service to

track the dissemination of published articles to discover where they are being discussed, bookmarked, and linked. This will also help publishers to answer questions such as, "Is use growing over time?" or, "Which articles or subjects areas are being seen more than others?", considering multiple web sites rather than only their own web site (Tolwinska 2015). DOIs are also used as tools in some studies addressing altmetrics, e.g. ensuring the link between bibliometric databases and altmetric sites (Haustein et al. 2015) or identifying articles (Haustein et al. 2014; Thelwall et al. 2013).

As mentioned before, DOIs and the development of their related services are increasingly important for academia at different levels (articles, research data, etc.). But the same is true for bibliometrics and altmetrics, which justifies studies focusing on the assignment of DOIs to scientific articles.

To the best of our knowledge, only one study has evaluated the implementation of DOIs in the scientific literature, using Scopus—which indexes several databases, including Embase, Medline or Biobase (Valderrama-Zurián et al. 2015)—and Web of Science Core Collection over the period 2005–2014 (Gorraiz et al. 2016). This study showed that "there are still journals with a large number of items still lacking DOIs in 2014" and this "should be alarming for the corresponding editors and should give them reason to enhance the formal quality and visibility of their journals…". The authors also encourage scientists to review their publication strategies and to favour publication channels with established DOI assignments to result in a higher web presence and visibility".

The objectives of the present study are:

- to assess the DOI availability of articles in biomedical journals indexed in the PubMed database, year by year, over the period 1966–2015 (50-year retrospective study),
- to evaluate the percentage of articles with DOIs in the PubMed database, published in 2015,
- to complete these investigations with a geographical analysis of the countries and continents of publishers in order to identify the countries and continents which assign the most and the least DOIs to articles. To the best of our knowledge, this type of analysis has never been performed.
- to identify the most productive journals in the field of biology and medicine which did not yet assign DOIs in 2015.

Materials and methods

The search for papers to be included in this study was carried out from March 22nd to April 20th, 2016 using the PubMed database (http://www.ncbi.nlm.nih.gov/pubmed), developed by the National Center for Biotechnology Information (NCBI) at the National Library of Medicine (NLM). PubMed was chosen because it is the most widely used bibliographic database in medicine (Falagas et al. 2008), and the country of publishers can be easily identified using the specific field "Country of Publication". However, contrary to other bibliographic databases (e.g. Scopus or Web of Science), any search tool is effective for distinguishing references with DOIs from others in PubMed. In PubMed, the interrogation of the field "Article Identifier" (which includes article identifiers submitted by journal publishers such as DOI) with the wildcard operator (e.g. 10* to extract all articles with a DOI) uses only the first 600 variations, because PubMed searches for the first 600 variations of a truncated term. It was then impossible to extract all references with DOIs using a

query to assess the availability of DOIs in PubMed articles. Therefore, references were randomly selected from PubMed according to their PubMed identifier (PMID) using a Hypertext Preprocessor language (PHP) function that generates random integers (the PHP random number generation function called mt_rand (min, max), which returns an integer between min and max). The minimum value used was 1, and the maximum value 26,995,803, corresponding to the higher PMID assigned in PubMed at the time of the experiment was done. Then, the randomly generated integer was used to query PubMed by PMID using Efetch Entrez Programming Utilities, in order to extract the reference of the corresponding article. Data were downloaded from PubMed in Extensible Markup Language (XML) and were processed through developed PHP scripts. They were then imported to Microsoft Excel 2013 (Microsoft, Redmond, USA) for data processing as done previously (Boudry et al. 2016; Boudry and Mouriaux 2015). The analysis was limited to the publication type "Journal Article". For each article, the existence of a DOI was verified, then the date of publication, the name of the journal, and the country of publishers were analyzed. When the country of publisher was absent in the reference, it was determined using the NLM catalog ("Home—NLM Catalog—NCBI" 2016). England, Scotland, Northern Ireland, and Wales were grouped into the United Kingdom. Countries were clustered by their continent according to the United Nations classification ("United Nations Statistics Division-Standard Country and Area Codes Classifications (M49)" 2016).

In order to assess implementation of DOIs year by year over the period 1966–2015, an analysis of 496,665 randomly selected articles published from 1966 to 2015 was done, corresponding to 2.29% of the articles included in PubMed (the total number of articles in PubMed was 21,680,488 on March 22nd 2016 for the same period). This first analysis was called "retrospective analysis" in this paper.

A second analysis of 268,790 randomly selected articles published in 2015 was done to evaluate the current implementation of DOIs (representing 21.68% of articles published in 2015 in the PubMed database). This second analysis was called "current analysis" in this paper. The year 2016 was not included because it was incomplete when the analysis was done, and a bias could have been introduced in the results when including journals with undefined frequencies of publication.

Results

Implementation of DOIs (retrospective analysis 1966–2015)

Among the 496,665 articles studied, the number of articles with DOIs was 201,055, corresponding to 40.78% of articles with a DOI. Figure 1 shows the percentage of articles with DOIs for articles published over the period 1966–2015. The percentage of articles with DOIs began to increase for articles published around the year 2000, with spectacular growth in the years 2002–2003, then reached a peak in 2015.

Implementation of DOIs: geographical analysis of countries and continents of publishers (retrospective analysis 1966–2015)

In the period 1966–2015, we identified 115 countries of publishers. As shown in Table 1, among the 50 most productive countries of publishers, publishers from South Korea

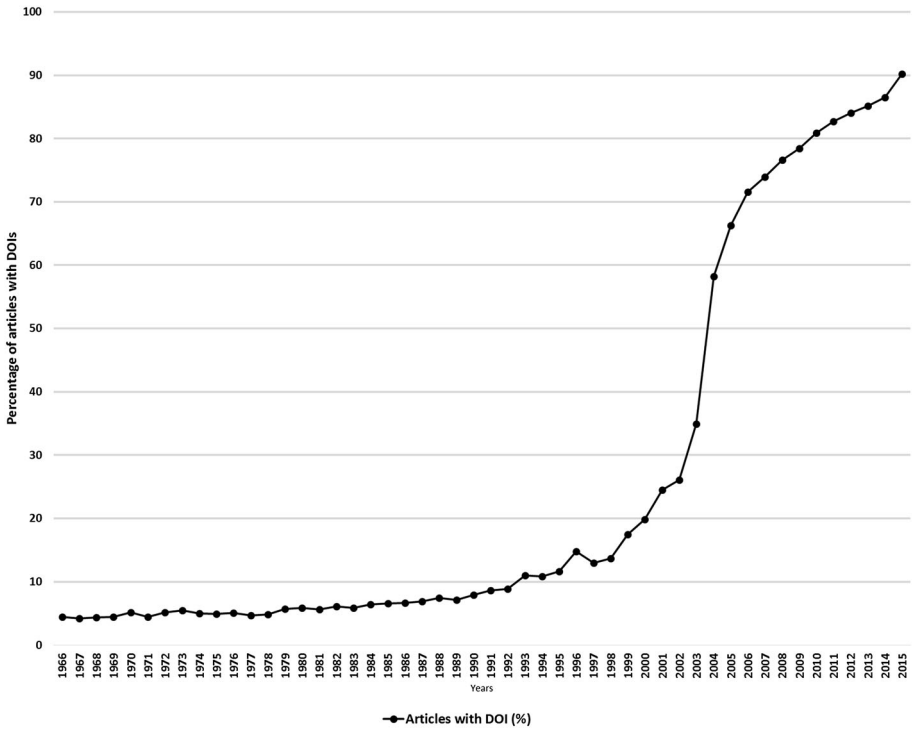

Fig. 1 Percentage of articles with DOIs in the PubMed database for articles published over the period 1966–2015 (retrospective analysis)

assigned the highest percentage of DOIs to articles, and publishers from seven countries assigned <1% of DOIs to articles they published over the period 1966–2015.

The analysis of the percentage of articles with DOIs published by the 10 most productive countries (Fig. 2) identified three groups of countries. The first includes 6 countries [France, Germany (1990–), Switzerland, the United Kingdom, the Netherlands, and the United States] where publishers massively assigned DOIs in the 2000s, to reach 85–99% of articles with DOIs in 2015. The second, with two countries (Japan, and China), began to assign DOIs after the first group and lagged behind the first group in 2015 (from 40 to 80% of articles with DOIs). The last group, with two countries, West Germany (–1990) and the USSR (–1991), had logically stopped their production in 1990 and 1991, when they ceased to exist, respectively. It is important to note that only publishers from three countries (the United States, Germany, and to a lesser extent the United Kingdom) made an effort to assign DOIs retrospectively before 1997, the year DOIs were launched by the IDF.

For continents, over the period 1966–2015 the percentage of articles with DOIs varied from 15.23% (Latin America and the Caribbean) to 45.47% (North America) of articles with DOIs (Table 2).

As shown in Fig. 3, three continents massively assigned DOIs in the 2000s: North America, Europe, and to a lesser extent Oceania. Asia, Latin America, the Caribbean, and Africa began later, around 2007/2008. Publishers from only two continents (North America and Europe) made an effort to assign DOIs retrospectively before 1997.

Table 1 Number of articles published, number of articles with DOIs and percentage of articles with DOIs for the 50 most productive countries of publishers over the period 1966–2015 (retrospective analysis)

Country of publisher	Number of articles	Number of articles with DOIs	Percentage of articles with DOIs	Country of publisher (continued)	Number of articles	Number of articles with DOIs	Percentage of articles with DOIs
United States	212,668	98,240	46.19	Norway	1658	297	17.91
United Kingdom	90,291	51,217	56.72	Korea (South)	1534	1180	76.92
Netherlands	27,079	12,770	47.16	Greece	1499	303	20.21
Germany (1990-)	19,595	13,117	66.94	Austria	1411	414	29.34
Japan	15,713	1718	10.93	Hungary	1173	176	15.00
Switzerland	11,588	4787	41.31	Romania	1001	10	1.00
France	11,463	2068	18.04	Mexico	810	7	0.86
West Germany (–1990)	10,717	917	8.56	South Africa	796	44	5.53
USSR (–1991)	9931	0	0.00	Yugoslavia (–2006)	681	0	0.00
China	8254	1041	12.61	Egypt	664	438	65.96
Italy	8083	807	9.98	Czech Republic (1993–)	659	16	2.43
Denmark	5760	1438	24.97	Thailand	643	0	0.00
Canada	5135	792	15.42	Israel	620	6	0.97
Poland	4716	270	5.73	Iran	601	161	26.79
India	4547	1768	38.88	Finland	594	9	1.52
Ireland	4294	2354	54.82	Turkey	588	126	21.43
Australia	4241	1408	33.20	Bulgaria	586	74	12.63
Spain	3571	542	15.18	Singapore	478	112	23.43
Russia (1991-)	3467	13	0.37	Pakistan	450	99	22.00
Sweden	2965	389	13.12	Ukraine (1991–)	443	0	0.00
Brazil	2712	602	22.20	Argentina	431	30	6.96
East Germany (–1990)	2595	36	1.39	Chile	347	88	25.36
Czechoslovakia (–1992)	2043	0	0.00	Saudi Arabia	307	47	15.31
Belgium	1822	97	5.32	United Arab Emirates	301	41	13.62
New Zealand	1760	710	40.34	Croatia (1991–)	276	20	7.25

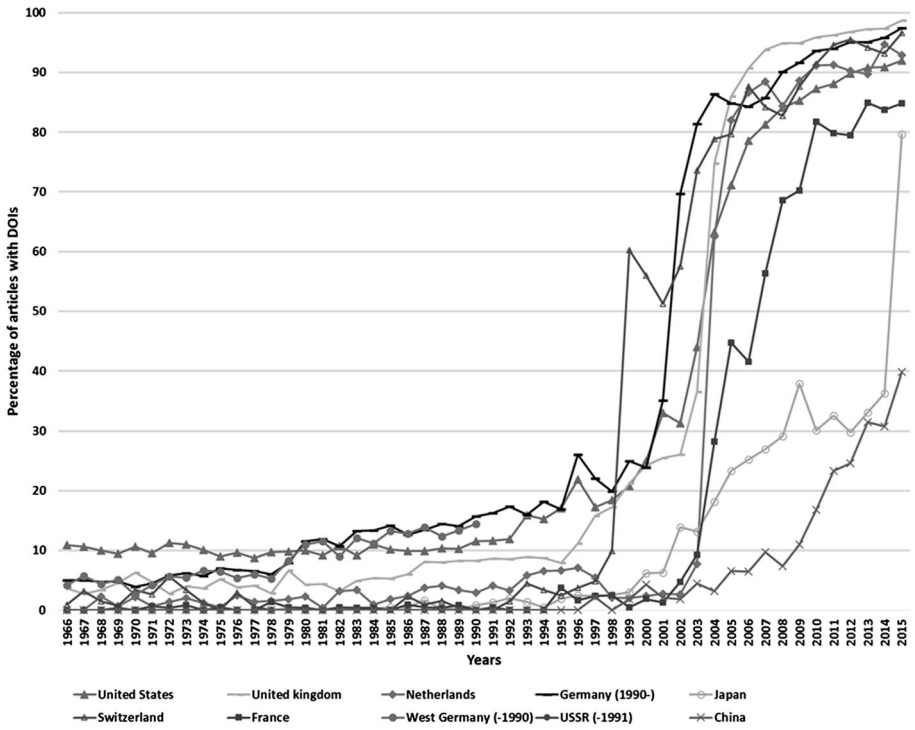

Fig. 2 Percentage of articles with DOIs in the PubMed database published over the period 1966–2015: the ten most productive countries of publishers (retrospective analysis)

Table 2 Number of articles published, number of articles with DOIs, and percentage of articles with DOIs for continents of publishers over the period 1966–2015 (retrospective analysis)

Continent of publisher	Number of articles	Number of articles with DOIs	Percentage of articles with DOIs
Europe	230,740	92,217	39.97
North America	217,803	99,032	45.47
Asia	34,756	6355	18.28
Oceania	6029	2118	35.13
Latin America and the Caribbean	4917	749	15.23
Africa	2420	584	24.13
World	496,665	201,055	40.48

Implementation of DOIs in 2015: geographical analysis of countries and continents of publisher (current analysis)

To evaluate the current implementation of DOIs, 268,790 articles published in 2015 were analyzed (corresponding to 21.68% of the total number of articles published in 2015

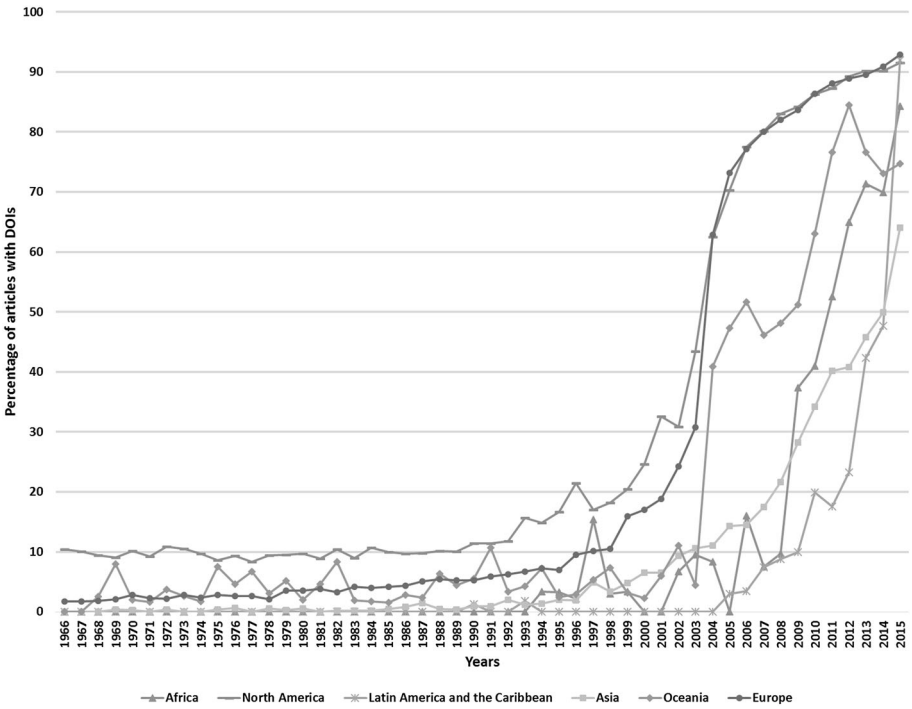

Fig. 3 Percentage of articles with DOIs in the PubMed database published from 1966 to 2015: continents of publishers

referenced in PubMed). Of these articles, 232,281 have DOIs, corresponding to 86.42% of the articles. We identified 79 countries of publishers. The 268,790 articles were published in 7600 journals. Out of these 7600 journals, 6445 (84.80%) assigned DOIs, 1155 (15.20%) did not assign DOIs to their articles.

Results of countries and continents of publishers are presented in Tables 3 and 4. Korea (South), Norway, and Uganda (but with only 2 journals for the two latter countries) were the countries where the percentage of journals using DOIs were the highest. Seven of the 50 most productive countries of publishers assigned <10% of DOIs to articles in 2015 (Israel, Malaysia, Mexico, Russia, Thailand, Ukraine and Serbia). In Russia, only 2 journals of 59 assigned DOIs to articles, representing 2.09% of articles with DOIs. Asia, in 2015, was the continent where the publishers implemented by far the least number of DOIs to articles (58.52%), while Europe led with 90.32% of articles with DOIs.

Table 5 lists the 20 most productive journals for articles published in 2015 (current analysis), based on the number of articles published, that did not assign DOIs to their articles.

Discussion

To our knowledge, there are no similar studies examining the availability of DOIs in publications archived by PubMed, and such a study of a geographical analysis of countries and continents of publishers has never been done. PubMed was chosen because, contrary to

Table 3 Number of articles published, number of articles with DOIs, percentage of articles with DOIs, number of journals, number of journals with DOIs, and percentage of journals with DOIs in the 50 most productive countries of publishers for the year 2015 (current analysis)

Country of publisher	Number of articles	Number of articles with DOIs	Percentage of articles with DOIs	Number of journals	Number of journals with DOIs	Percentage of journals with DOIs
United States	118,291	105,529	89.21	2810	2427	86.37
United Kingdom	62,944	61,364	97.49	1724	1667	96.69
Netherlands	14,242	12,893	90.53	479	439	91.65
Germany	12,014	11,559	96.21	393	373	94.91
Switzerland	10,722	10,266	95.75	248	236	95.16
China	6169	1934	31.35	140	73	52.14
India	4838	4124	85.24	168	145	86.31
Japan	4497	3403	75.67	164	122	74.39
New Zealand	3490	2495	71.49	124	119	95.97
Italy	2840	1417	49.89	113	63	55.75
France	2594	2186	84.27	96	84	87.50
Canada	2065	1127	54.58	87	40	45.98
Australia	2043	1509	73.86	83	66	79.52
Korea (South)	1826	1733	94.91	120	119	99.17
Ireland	1762	1710	97.05	38	36	94.74
Brazil	1660	1646	99.16	60	59	98.33
Russia	1582	33	2.09	57	2	3.51
Poland	1412	875	61.97	72	47	65.28
Spain	1329	1011	76.07	63	49	77.78
Iran	1245	622	49.96	78	28	35.90
Greece	1044	395	37.84	19	9	47.37
Sweden	892	237	26.57	29	9	31.03
Denmark	854	596	69.79	30	26	86.67
Turkey	813	387	47.60	31	19	61.29
Thailand	654	1	0.15	4	1	25.00
Egypt	540	510	94.44	68	65	95.59
Uganda	492	492	100.00	2	2	100.00
Pakistan	466	74	15.88	10	4	40.00
United Arab Emirates	445	117	26.29	38	5	13.16
Czech Republic	364	48	13.19	20	5	25.00
Romania	333	45	13.51	13	3	23.08
Bulgaria	312	284	91.03	8	6	75.00
Austria	302	299	99.01	19	17	89.47
Hungary	274	220	80.29	16	9	56.25
Singapore	266	197	74.06	14	12	85.71
Belgium	263	60	22.81	14	2	14.29
Saudi Arabia	242	185	76.45	9	7	77.78
Mexico	232	21	9.05	9	3	33.33

Table 3 continued

Country of publisher	Number of articles	Number of articles with DOIs	Percentage of articles with DOIs	Number of journals	Number of journals with DOIs	Percentage of journals with DOIs
Croatia	204	31	15.20	12	4	33.33
Ukraine	193	0	0.00	8	0	0.00
Israel	161	9	5.59	6	1	16.67
South Africa	153	30	19.61	10	5	50.00
Slovakia	142	47	33.10	5	2	40.00
Argentina	127	34	26.77	8	4	50.00
Norway	123	123	100.00	2	2	100.00
Malaysia	108	0	0.00	7	0	0.00
Serbia	107	0	0.00	3	0	0.00
Bosnia and Herzegovina	105	95	90.48	6	5	83.33
Chile	97	65	67.01	4	3	75.00
Finland	93	15	16.13	2	1	50.00

Table 4 Number of articles published, number of articles with DOIs, percentage of articles with DOIs, number of journals, number of journals with DOIs, and percentage of journals with DOIs by continent of publishers for the year 2015 (current analysis)

Continent of publisher	Number of articles	Number of articles with DOIs	Percentage of articles with DOIs	Number of journals	Number of journals with DOIs	Percentage of journals with DOIs
North America	120,356	106,656	88.62	2897	2467	85.16
Europe	117,199	105,856	90.32	3500	3100	88.57
Asia	22,061	12,910	58.52	806	545	67.62
Oceania	5533	4004	72.37	207	185	89.37
Latin America and the Caribbean	2256	1783	79.03	94	73	77.66
Africa	1385	1072	77.40	96	75	78.13
World	268,790	232,281	86.42	7600	6445	84.80

other databases (Web of Science, Scopus), the country of publisher can be easily identified because of a specific field (called Country of Publication). Scopus did not provides this information, even when using the downloading format "all available information". The Web of Science provides a specific field called "Publisher Address" containing the complete address of the publisher, implying manual or automated isolation of the country from this complete address, which was not only impossible to carry out given the number of articles analyzed in the study, but could be a source or error.

Only one study, published in 2015 (Gorraiz et al. 2016), has assessed the availability of DOIs in Web of Science Core Collection and Scopus over the period 2005–2014. This work showed that, in 2014, the percentage of citable documents (articles, reviews and

Table 5 The 20 most productive journals lacking DOIs: name of the journal, number of articles published, name of the publisher, country of publisher, ISSN and language of publication for articles published in 2015 (current analysis)

Journal	Number of articles	Publisher	Country of publisher	ISSN	Language of publication
Int J Clin Exp Med	1187	e-Century Publishing	United States	1940-5901	English
Int J Clin Exp Pathol	786	e-Century Publishing	United States	1936-2625	English
J Nanosci Nanotechnol	546	American Scientific Publisher	United States	1533-4880	English
Asian Pac. J. Cancer Prev.	504	Asian Pacific Organization for Cancer Prevention	Thailand	1513-7368	English
Stud Health Technol Inform	466	IOS Press	Netherlands	0926-9630	English
Anticancer Res.	379	International Institute of Anticancer Research	Greece	1791-7530	English
Nippon Rinsho	282	Nippon Rinsho Co	Japan	0047-1852	Japanese
Eur Rev Med Pharmacol Sci	257	Verduci Editore	Italy	2284-0729	English
Zhonghua Yi Xue Za Zhi	224	Zhonghua yi xue hui	China	0376-2491	Chinese
Zhongguo Zhong Yao Za Zhi	220	Zhongguo yao xue hui	China	1001-5302	Chinese
Lakartidningen	204	Sveriges Lakarforbund	Sweden	1652-7518	Swedish
Rev Med Suisse	204	Médecine et Hygiène	Switzerland	1660-9379	French
Guang Pu Xue Yu Guang Pu Fen Xi	195	Beijing da xue chu ban she	China	1000-0593	Chinese
Ugeskr. Laeg.	180	Den Alm Danske Laegerforening	Denmark	1603-6824	Danish
Lin Chung Er Bi Yan Hou Tou Jing Wai Ke Za Zhi	170	Lin chuang er bi yan hou tou jing wai ke za zhi bain ji bu	China	1001-1781	Chinese
Am Surg	167	Southeastern Surgical Congress	United States	1555-9823	English
Huan Jing Ke Xue	166	Ke xue zhu ban she	China	0250-3301	Chinese
Ned Tijdschr Geneeskd	162	Bohn Stafleu van Loghum	Netherlands	1876-8784	Dutch
Nat Prod Commun	161	Natural Product Communications	United States	1934-578X	English
J Pak Med Assoc	155	Pakistan Medical Association	Pakistan	0030-9982	English
Nan Fang Yi Ke Da Xue Xue Bao	152	Nanfang yi ke da xue xue bao bian ji bu	China	1673-4254	Chinese
Curr. Pharm. Des.	151	Bentham Science Publishers	Netherlands	1873-4286	English
Am Fam Physician	150	American Academy of General Practice	United States	1532-0650	English
Pak J Pharm Sci	138	Faculty of Pharmacy, University of Karachi	Pakistan	1011-601X	English

Table 5 continued

Journal	Number of articles	Publisher	Country of publisher	ISSN	Language of publication
Zhongguo Shi Yan Xue Ye Xue Za Zhi	136	Zhongguo shi yan xue za zhi she	China	1009-2137	Chinese, English
Oncology (Williston Park, N.Y.)	132	Williston Park	United States	0890-9091	English
Ying Yong Sheng Tai Xue Bao	120	Ying yong sheng tai xue bao bian ji wei yuan hui	China	1001-9332	Chinese
Zh Nevrol Psikhiatr Im S S Korsakova	119	Meditsina	Russia (Federation)	1997-7298	Russian
J Med Assoc Thai	116	Medical Association Of Thailand	Thailand	0125-2208	English, Thai
Gan To Kagaku Ryoho	113	Gan to Kagaku Ryōhōsha	Japan	0385-0684	Japanese

proceeding papers) with DOIs in Scopus was about 86% in the health sciences, and 89% in life science. Our results are quite similar: 86.47% of articles had DOIs in PubMed in 2014.

The retrospective analysis of availability of DOIs over the period 1996–2015 has shown that the percentage of articles with DOIs began to increase for articles published in and around the year 2000, with spectacular growth in the years 2002–2003, corresponding quite logically to the years following the launch of DOIs by the IDF. This showed that the DOI system was massively adopted by publishers in the years 2002–2003, meaning that most publishers rapidly understood the numerous advantages related to this system. It is noticeable that the highest percentages of articles with DOIs are mainly found in countries where large scientific publishers dominate (i.e. the United States, the United Kingdom, the Netherlands) and which have been identified by Vardakas et al. (2015) as the most productive countries of publishers in PubMed over the period 2004–2013. Of note is that unfortunately, overall, little effort has been made to assign DOIs retrospectively to articles published before 2000. This is regrettable because this retrospective assignment of DOIs could permit the enhancement of the value of former articles by facilitating their visibility and accessibility.

The current analysis of articles published in 2015 showed that there were still 13.58% of articles that did not have DOIs, corresponding to 15.20% of journals indexed in PubMed which did not yet use DOIs. Publishers who do not assign DOIs must be made aware of the implications and realize, as some already have, the important role DOIs can play in identifying published articles more easily as well as increasing their journal's impact (Braile 2011). More importantly, some scholars state that, in the near future, the value of a publication will be determined by the number of links to it (Wang 2007). Moreover, all of these articles and journals could be excluded from some scientific production evaluations or altmetric measurements, particularly that of the promising service CrossRef Event Data, whose objectives are to track activity surrounding articles or research data with DOIs from potentially any web source. The geographical analysis of countries and continents of publishers showed a high amount of heterogeneity in countries and continents. The analysis also demonstrated that seven of the 50 most productive countries of publishers assigned <10% of the DOIs to articles in 2015 (Israel, Malaysia, Mexico, Russia, Thailand, Ukraine and Serbia). For continents, in 2015 Asia was behind in both the percentage of

articles with DOIs and the percentage of journals which had implemented DOIs. The reason for these observations is difficult to interpret because it is an arduous task to determine whether recommendations for publishers to promote DOIs have been specifically implemented in countries or continents. It seems that few countries have implemented this type of recommendation (Gorraiz et al. 2016). Globally, recommendations to promote DOIs can be found in "Recommended Practices for the Presentation and Identification of E-Journals (PIE-J)" ("RP-16-2013 PIE-J (short URL)—National Information Standards Organization" 2013) published in 2013 by the National Information Standards Organization (NISO). Furthermore, the Policy Recommendations for the Open Access to Research Data in Europe (RECODE) project have also published such recommendations: "Publishers should require that data accompanying their publications are citable, and provide clear guidelines for data citation. Data citation should include DOIs" ("RECODE" 2015). As suggested by Park et al. (2011), the further promotion of the core features of the DOI systems, perhaps through case examples and direction from industry/governmental leaders, are essential supporting factors in influencing the promotion of the DOI system's success. Industries and governments that develop DOI-compatible systems are encouraged to promote its features, which should be a powerful influence among organizations that are considering adopting DOI systems. This should have a significant influence on the countries identified in this study as assigning few DOIs, and may convince them to establish recommendations to encourage their publishers to consider using DOIs.

Additionally, the list of the 20 most productive journals lacking DOIs for articles published in 2015 (current analysis), suggests that small and local publishers are mainly implicated. The cost of DOIs may explain the unwillingness of small publishers to implement them. Nevertheless, publisher fees are proportional to the total publishing revenue, and the deposit fees per DOI (from 0.06 to 1.00 US dollar per content type) do not seem, in any case, to be an impenetrable barrier to the adoption of DOIs ("crossref.org :: publisher fees" 2016). Technical requirements to implement DOIs may also hinder small publishers who work in a traditional way. Nevertheless, it is difficult to believe that in some countries, as in Russia, the 55 of 59 journals that have not implemented DOIs are small publishers, and that the cost and technical requirements could explain this finding. Only a qualitative survey among publishers in different countries would be able to clarify these results. The present study should also encourage publishers who have not yet assigned DOIs to change their strategy in order to benefit from the numerous advantages offered by the system, as specified in the present article. They should understanding that with the new developments surrounding DOIs they may be increasingly on the fringes of scientific publication.

For publishers that have already adopted DOIs for their articles, a way to improve the efficiency of their utilization may be to assign several DOIs referring to different parts of articles (e.g. tables, figures, videos, audio clips, datasets and supporting information), thereby allowing their access as separate entities (see as examples articles published by PLOS One) (DeRisi et al. 2003). As in the case of CrossRef membership publishers ("DOI display guidelines" 2016), suggesting researchers to routinely mention DOIs in references in their instructions to authors would improve researchers' level of awareness of DOIs, and would also allow the readership to move from one article to another at the citation level, regardless of journal publisher. Without full-text citation linking, the user who discovers a desired resource while reading usually has to switch to a different search interface to locate and ultimately access that resource. With DOIs, it only takes a click or two to get to the full text, either as an authorized user or through pay-per-view services ("crossref.org" 2016).

Researchers should be aware that choosing journals that assign DOIs is important, enabling their scientific communications to be more visible and accessible, and ensuring that they can benefit from new metrics such as altmetrics. Moreover, it increases the likelihood that their work will be read and cited.

The results presented in this article pertain only to biomedicine articles from PubMed and includes only articles [the study of Gorraiz et al. (2016) studied three types of publications: all document types from journals, proceedings series and conferences, and books extracted from Scopus and Web of Science Core Collection]. These authors have shown that the social sciences and humanities have lower percentages of documents with DOIs compared to health, life, and physical sciences. It would be useful to complete their study by carrying out a geographical analysis as done in this study, particularly in the social sciences and humanities where practices and issues are different. Furthermore, as some studies have shown that publishing articles in open access journals increases their visibility and therefore increases the number of times they are cited in other articles (Swan 2010), future studies should explore whether there is a relationship between the assignment of DOIs and the number of citations received by articles.

The advantages of developing standards for services are central, DOIs do not waver from this rule. Hence, the increasing use of DOIs should result in the multiplication of useful applications for all those involved in scientific research. In the future, DOIs should become increasingly helpful tools. For this to continue, efforts must be made to generalize their use by publishers, without exception, and in all countries and continents. This should have the consequence of familiarizing researchers with DOIs by means of articles they read, which will allow, in the near future, the development and extension of the use of DOIs to research data. However, errors in assigning DOIs, notably incorrect assignment of a single DOI to multiple articles by bibliometric databases, which exist today (Franceschini et al. 2014), should be limited.

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