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ORIGINAL ARTICLE

Trends in World Dental Research: an overview of the last three decades using the Web of Science

R. Pulgar · I. Jiménez-Fernández · E. Jiménez-Contreras · D. Torres-Salinas · C. Lucena-Martín

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Abstract
Objective The objective of this paper is to analyse the scientific activity of dental sciences over the last 30 years.
Materials and methods Dental-research output was identified by retrieving all citable dental documents in the Web of Science (WoS) database in the periods 1986–1988, 1996–1998, and 2006–2008. For this, a two-phase search strategy was designed: firstly, output in Dentistry, Oral Surgery, and Medicine (DOSM) Journal Citation Reports (JCR) category journals were compiled; secondly, for journal documents of other JCR categories but related to Dentistry (Non-DOSM), an innovative search strategy was designed based on a double criterion, thematic and institutional.
Results The results showed that DOSM production increased in absolute but decreased in relative terms over the last 30 years. The JCR categories where dental researchers publish also varied. Surprisingly, the geographic distribution of the production shows a growing concentration of the steadily fewer countries, a previously undescribed phenomenon, while the thematic analysis reveals that this production continued to form four broad thematic areas encompassing the remaining specialties: Dental Materials Prosthodontics, Orthodontics, and General Dentistry.
Conclusions Scientific production in dentistry has changed in the past three decades both quantitatively and qualitatively, as well as their geographical distribution despite being structured around the same specialties.
Clinical relevance In this study, along with some key messages about the key shifts in publication trends, in terms of subject, where published and by whom, we propose a new methodology which could be useful to professionals as well as researchers, in which the exhaustivity and precision rates for scientific information retrieval improve.

Keywords Dental research · Dentistry · Publications · Journal impact factor · Bibliometrics · Biomedical research

Introduction

Dentistry, as a science, has achieved a high level of maturity in recent decades. Solla-Price's seminal work on the exponential growth of science established that publications have doubled in fixed time periods [1]. However, no studies document whether Dentistry fits this pattern, raising certain questions: how has dentistry research evolved during recent decades? Has the quantity or the quality of dental articles changed, and, if so, how?

Bibliometrics, a systematic method for evaluating research output, can help track changes in scientific interests over time, providing insights into both qualitative and quantitative research trends [2]. The analysis of scientific production in specific areas highlights emerging themes and relationships between disciplines, indicating possible advances in the near future [3, 4].

However, research analysis in biomedical fields, is complex. No methodology yet fully satisfies the needs of researchers, institutions, and scientific administrators, although the analysis of publications remains a predominate approach [5, 6], especially using MEDLINE or the journals

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R. Pulgar · I. Jiménez-Fernández · C. Lucena-Martín
Department of Stomatology, Faculty of Dentistry,
Campus de Cartuja, Ed. Máximo, Granada University,
18071 Granada, Spain

E. Jiménez-Contreras (✉) · D. Torres-Salinas
Ec3 Research Group & CIMA-Center for Applied Medical Research, Campus de Cartuja, Ed. Máximo,
Granada University,
18071 Granada, Spain
e-mail: evaristo@ugr.es

of a category of the Journal Citation Reports (JCR) in Web of Science (WoS) databases [2, 7, 8].

Apart from methodological problems, several phenomena determine the difficulty of this analysis, especially in Dentistry. On one hand, with the publication surge, authorship and collaborative efforts with other disciplines have burgeoned [9], so that part of the production is published in non-specialty journals. On the other hand, the loss of unitariness in dental knowledge, as has happened in other biomedical disciplines [8], could be leading to a potentially irreversible differentiation process, splintering knowledge into numerous isolated subdisciplines and specialties. Thus, attempts at a comprehensive portrayal of ongoing scientific research and innovation in the dental sciences have become enormously complex, thus requiring new methodologies.

Our aim was to analyse the scientific activity of dental sciences in the last 30 years. The Thomson Reuter WoS database was used to reach three specific objectives: (a) design a new methodology permitting the retrieval of dental articles published in journals outside the category Dentistry, Oral Surgery, and Medicine (DOSM) of the JCR; (b) characterize the dental research in relation to output, authorship, geographic origin, and impact; and (c) thematically characterize research in dental specialties, evaluating their interactions and analysing their trend over the last three decades.

Material and method

The database selected to analyse dental-research output was the Thomson Reuters WoS. For three periods, 1986–1988, 1996–1998, and 2006–2008, all citable documents (articles, reviews, letters, and notes) published in any language were considered. The searches spanned October 2009 to March 2010.

The documents were retrieved in two stages: first, all documents published in the journals included in DOSM category of the JCR database for the 3-year periods were directly downloaded. Secondly, to retrieve dental documents published in any other journals included in any other categories of the JCR database, hereafter called Non-DOSM, we first had to establish a specific methodology. We defined "dental literature" as any scientific document with content related to dental subjects (i.e. "lip" could be a dental subject but also dermatological) and produced by a dental institution, identified through its *institutional address*. Therefore, a thematically mixed search strategy as well as institutional was designed. The keywords to conduct the thematic search were selected by three of the authors (I.J., R.P., and C.L.) of the Stomatology Department of the University of Granada (Spain). They screened the thesaurus Medical Subject Heading (MeSH) of MEDLINE and independently selected the descriptors related to Dentistry. All terms included in the general descriptor *Dentistry* were selected (n=183). Other dental descriptors of the thesaurus were also selected (n=46); in doubtful cases, uncertainties were resolved by open discussion, and finally, a total of 229 terms were used. All the descriptors are shown in Online Resource 1.

Then, bibliographic software (Procite), was used to make the institutional search. The most frequent institutional terms in the field a*ddress* of the DOSM category databases previously generated were identified. The term related to Dentistry can appear in the address as a department name (e.g. Acta, Dept. Periodontol, Amsterdam, Netherlands), as the name of an institution (e.g. Acad Orthodont Assisting, Kennesaw, GA, USA) or both at once (e.g. Acad Ctr Dent Amsterdam, Dept Oral Microbiol, NL-1066 EA Amsterdam, Netherlands). A search strategy was adopted, taking advantage of a useful operation called *truncation* that can be used for word searches in a text. The truncated term used (present in the 80 % of the records) were: *dent**, *oral**, *maxillof**, *orthodont**, *periodont**, *odontol**, *prosthodont**, *endodont**, and *stomatol**.

After the descriptors were selected and the terms associated with dental institutions were identified, the mixed (subject + address) search strategy was performed. We worked together on the fields *Topic* (with 229 terms of the MeSH) and *Address* (consistently with the complete list of the truncated terms) joined by the Boolean operator *AND*. (i.e. Topic: Apicoectomy AND Address: dent* OR oral* OR maxillof* OR orthodont* OR periodont* OR odontol* OR prosthodont* OR endodont* OR stomatol*). For example, applying this procedure to this supposition, in the period 2006–2008, the results were the following: the term apicoectomy generated 21 results. With the filter of the address, 18 documents were recovered, by which 3 records were discarded; two of these corresponded to works related to research in veterinarian odontology while a third, which was genuinely a dentistry article, belonged to a dentistry journal and was thus recovered despite that the address indicated no dental institution. Afterwards, in Non-DOSM databases, duplicated records were eliminated.

The resulting database was analysed by six bibliometric indicators, calculated as specified in Table 1, which quantifies the time course of the output in the area as well of the subspecialties, the impact of these in the context of Dentistry as opposed to other categories as well as the time course of authorship.

The geographic origin of the documents was analysed by a multiple-count approach; each document was assigned to all countries appearing in the *address* field. The workload of each researcher being unknown, this was an unbiased way of analysing the efforts of each country [10]. For the bibliometric indicators used, see Table 1.

To allocate papers to subject areas, we considered dental specialties recognized by the American Dental Association (ADA) [11]. These specialties are Endodontics, Orthodontics and Dentofacial Orthopedics, Oral and Maxillofacial

Table 1 Bibliometric indicators formulae used in the study

Indicator	Explanation	Formula
NDOC and %DOC: Number and percentage of documents	The origin of documents is assessed using the address field. A document signed by authors from different countries is assigned to each country with equal value.	$\mathrm{NDOC} = \mathrm{doc}_1 + \mathrm{doc}_2 + \ldots \mathrm{docn}$ $\%\mathrm{DOC} = \left(\mathrm{NDOC}^{*}100\right)/\mathrm{Total\ doc\ sample}$
NAUT: Number of authors	This is the mode for the number of authors that sign the citable works.	NAUT = Mode of the number of authors per paper
%1Q: percentage of documents published in journals of the first quartile of any of the JCR categories	The normalization of the IF by quartiles consists of calculating the statistic quartile in which the journals appear in the JCR within their category according to their IF, with the aim of classifying them into four areas that indicate their position in the ranking. The journals belonging to the first quartile are those in the 25 % of the distribution of the IF with the best values and thus are the most prestigious. Thus the differences in IF between the different categories are overcome. The indicator N1Q counts the number of documents published in journals of the first quartile of any of the categories of the JCR and gives the %1Q which is the percentage of published documents in these journals with respect to the total of the documents of the sample.	$\mathrm{N1Q} = \mathrm{doc\ 1Q}_1 + \mathrm{doc\ 1Q}_2 + \ldots \mathrm{doc\ 1Qn}$ $\%1\mathrm{Q} = \left(\mathrm{N1Q}^{*}100\right)/\mathrm{Total\ doc\ sample}$
%T3: percentage of documents published in the three JCR journals with highest impact factor (Top3)	NTop3 expresses the total number of documents published in the three JCR journals with highest IF (Top3). This indicator gives rise to the %Top3 (%T3), the percentage of documents from the "Top 3" with respect to the total number of documents in the sample.	$\mathrm{NTop3} = \mathrm{doc\ Top3}_1 + \mathrm{doc\ Top3}_2 + \ldots \mathrm{docTop3n}$ $\%\mathrm{Top3} = (\mathrm{NTop3} \times 100)/\mathrm{Total\ doc\ sample}$
NIF: Normalized IF	The Average IF (AIF) of a category (AIFc) is calculated by dividing the sum of the IF of the journals of the category by the total number of journal of that category. The AIF of a sample of documents published in journals of one category (AIFs) is calculated by dividing the sum of the IF of the journal of each document by the total number of documents of the sample. The result of dividing the AIFs by the AIFc is the Normalized IF (NIF). The values of NIF can be distributed into three ranges: If NIF >1 sample above the mean of the category If NIF = 1 sample equal to the mean of the category If NIF <1 sample below the mean of the category	$\mathrm{NIF} = \mathrm{AIFs}/\mathrm{AIFc}$ $\mathrm{AIFc} = \sum \mathrm{IF\ journals\ categ}/\mathrm{N\ journals\ category}$ $\mathrm{AIFs} = \sum \mathrm{IF\ journal\ documents}/\mathrm{N\ doc}$
CAVG: Citation average	Relativize the number of citations (NCit) with the number of citable documents through a division by what gives the average of citations reached by the documents	CAVG = NCit/N citable doc

JCR journal citation reports, *IF* impact factor

Pathology, Pediatric Dentistry, Periodontics, Prosthodontics, Dental Public Health, Oral and Maxillofacial Radiology, and Oral and Maxillofacial Surgery. General Dentistry was also included and represents dental fields not included in the above-mentioned specialties, i.e. those basically related to Operative Dentistry. Also, we consider including Dental Materials and Implants because they are interest areas with a well-defined body of evidence based on scientific and clinical knowledge.

For the documents of the databases, both DOSM as well as Non-DOSM, to be associated with the dental specialties considered, an allocation strategy of keywords based on the previously selected keywords (229 descriptors) in the MESH was created. General terms such as *tooth* or *enamel* were deleted because they introduced excessive noise and because if the article concerned Dentistry, it could always be recalled by other more specific terms. Of the remaining

terms, many shared a common root, and therefore were submitted to a process of lemmatization. This gave rise to a final list of 77 basic descriptors; these truncated terms being assigned to one or more dental specialties (Table 2). In this way, when one of these terms appears in the title, key words or a summary of an article, this record is labelled with the specialty or specialties previously associated with this term (i.e. record in the title, key words, or abstract of which appear the term *periapic** is labelled with the specialties Periodontics and Endodontics). Thus, when an article covers various themes at a time, using several of the truncated terms associated with several specialities, it is labelled simultaneously with these different specialties, offering us therefore information on how to relate these different disciplines within Dentistry.

Finally, the Social Networks Analysis (SNA) [12, 13] provides a graphic view of the relations between different pairs of specialties. In the network, the specialties are represented by nodes, and the number of documents that they share, by lines. To establish the strengths between the disciplines in each of the periods analysed, the total relations between pairs was calculated, representing in the network only those relations between pairs that jointly accumulated 75 % of the relations. The visualization algorithm used was the Kamada-Kawai [14], which calculates the total balance of the graph, as the square summation of the differences

Table 2 Truncated terms assigned to one or more dental specialties

	Sp specialties	Truncated descriptors
Descriptors assigned only to a specialty	Endodontics	endodont*, pulp*, retrogr*, canal*
	General[a]	cavity*, operat*, post*, core*, bleach*
	Implantology	implant*
	Materials[b]	material* biocompat* biopolym*, solder*, clasp*
	Orthodontics[c]	orthodont*, anchorag*, applianc*, bracket*,retain*, wire*, correctiv*, intercept*
	Pathology[d]	pathol*, cari*
	Pediatric[e]	pediat*, child*
	Periodontics	periodont* curettage* gingiv*
	Prosthodontics	prosthodont*, prosthes*, denture*, crown* centric*, articula*
	Public Health[f]	preventiv*, public*, care*,educat*,fluoride*,hygiene*, dentifric*, remineral*, sealant*
	Radiology[g]	radiograph*, panoramic*, bitew*
	Surgery[h]	surg*, glosect*, apicoect*
Descriptors assigned to various specialties	Endodontics & Periodontics	periapic*
	General[a] & Materials[b]	resin*, matrix*, inlays*, electrogalvanism*, dam*, adhesiv*, etching*
	General[a], Materials[b], Orthodontics[c], Pediatric[e] & Prosthodontics	bonding*
	General[a], Materials[b] & Prosthodontics	veneer*, alloy*
	General[a], Orthodontics[c] & Prosthodontics	bite*, impres*, model*, occlus*, esthet*
	General[a] & Prosthodontics	restorat*, pin*
	Implantology, Materials[b] & Prosthodontics	abutment*
	Implantology, Periodontics & Surgery[h]	regenerat*
	Materials[b], Orthodontics[c] & Prosthodontics	cement*
	Periodontics & Public[f]	prophyl*, plaque*, toothbrush*, index*
	Periodontics & Surgery[h]	membran*

[a] General Dentistry

[b] Dental Materials

[c] Orthodontics and Dentofacial Orthopedics

[d] Oral and Maxillofacial Pathology

[e] Pediatric Dentistry

[f] Dental Public Health

[g] Oral and Maxillofacial Radiology

[h] Oral and Maxillofacial Surgery

between the ideal distance and the actual distance for all vertices. With this methodology, therefore, it can be determined which of the specialties are most related, how this relationship develops over time, and what the general configuration of Dentistry is in each of the periods according to the position that the specialties occupy.

Results

The databases generated contained 55,056 citable documents, 49,369 being original articles, 2,076 review articles, 3,138 letters, and 473 notes. Among these, 88.44 %, (48,692 documents) were published in DOSM journals and the rest, 11.56 % (6,364 documents), in other JCR categories (Non-DOSM) (Fig. 1a, see Table 1 for bibliometric indicators). The output increased more in Non-DOSM (5.7-fold) than in DOMS (1.56-fold) between the first and last period studied. The cited average (CAVG) in DOSM was consistently lower than in Non-DOSM categories for the three periods. Regarding the number of authors, the mode was invariably greater in Non-DOSM than in DOSM. Figure 1b shows the 20 top-ranking countries in production (%DOC) and Table 3 shows the output in absolute values. The USA, UK, and Japan headed output for the three periods studied.

The most productive Non-DOSM categories and their output and impact indicators are listed in Fig. 2 for the three 3-year periods. The JCR categories Surgery and Biochemistry & Molecular Biology remained among the top 10 in the three periods. Pharmacology & Pharmacy, Radiology & Nuclear Medicine, and Otorhinolaryngology disappeared from the top during the second and third periods. Meanwhile, Biomedical Engineering & Materials Sciences and Biomaterials, absent from the top ten in the first period, led in the second and third period in output and quality. In both cases, the quality indicators, showed that the articles signed by dentists had values exceeding the mean of the category where published.

Figure 3 shows the output distribution by specialties for the three periods, with the output and impact indicators of the DOSM and Non-DOSM categories. General Dentistry was the most productive area in the three periods in DOSM and Non-DOSM, save the first period of Non-DOSM, when the top specialty was Public Health.

1.a. General Indicators	Period		NDOC	CAVG	NAUT	% Non-DOSM / DOSM	% DOSM / World	% Dentistry / World
	86-88	DOSM	13004	12.89	1	4.68%	0.85%	0.89%
		Non-DOSM	608	15.27	2			
	96-98	DOSM	15456	12.53	1	14.97%	0.71%	0.82%
		Non-DOSM	2313	16.47	3			
	06-08	DOSM	20232	1.36	4	17.02%	0.76%	0.89%
		Non-DOSM	3443	1.72	5			

1.b. %DOC per country	DOSM				Non-DOSM			
	86-88	96-98	06-08	Trend	86-88	96-98	06-08	Trend
USA	21,31%	24,40%	22,36%		21,38%	28,88%	25,50%	
United Kingdom	11,00%	11,39%	9,30%		14,64%	12,97%	9,64%	
Japan	3,56%	8,31%	9,14%		16,94%	25,81%	15,42%	
Germany	6,55%	3,46%	6,72%		3,45%	3,16%	6,13%	
Sweden	5,63%	4,96%	3,15%		3,95%	3,24%	2,50%	
Brazil	0,18%	1,31%	8,26%		0,66%	1,12%	8,92%	
Netherlands	3,07%	2,99%	3,06%		1,64%	2,77%	2,38%	
Italy	0,45%	2,36%	4,43%		0,66%	2,33%	4,65%	
Australia	2,68%	2,34%	2,53%		1,97%	1,69%	2,85%	
Turkey	0,18%	1,26%	4,92%		0,16%	0,39%	4,01%	
Canada	2,48%	0,91%	3,06%		6,25%	5,06%	3,51%	
France	2,15%	1,31%	1,64%		3,45%	3,42%	3,92%	
Finland	2,07%	2,02%	1,56%		3,45%	2,77%	1,71%	
China	0,12%	0,41%	3,53%		0,82%	0,73%	5,95%	
Switzerland	0,98%	1,84%	2,51%		1,64%	0,99%	1,77%	
Israel	1,81%	1,70%	1,45%		2,47%	2,46%	1,89%	
Denmark	1,84%	1,48%	1,24%		2,63%	1,77%	0,93%	
Norway	2,00%	1,44%	0,99%		1,15%	1,51%	1,05%	
Spain	0,19%	1,02%	1,85%		0,16%	0,99%	1,34%	
South Korea	0,07%	0,34%	2,04%		0,16%	0,69%	3,83%	

Fig. 1 **a** General bibliometric indicators (see Table 1) of the database. Dentistry, Oral Surgery, and Medicine, DOSM; other JCR categories, Non-DOSM. "% Dentistry" is the relative dental production, DOSM + Non-DOSM in Web of Science, representing the percentage of the total production of dentistry with the rest of the sciences. **b** Geographic analysis of the scientific output in Dentistry: relative data (%DOC). Top-20-ranking countries in terms of production with respect to the total of each period studied. The countries are arranged according to their absolute total production in the three periods analysed (see Table 3). Production variation in the three quarters studied can be seen graphically in "Trend"

Table 3 Production (NDOC and %DOC) per country, in DOSM and Non-DOSM in the three periods studied, arranged according to their total output

		DOSM								Non-DOSM								Total	
		86–88		96–98		06–08				86–88		96–98		06–08					
1	USA	2,771	*21%*	3,772	*24%*	4,523	*22%*	11,066	23%	130	*21%*	668	*29%*	878	*26%*	1,676	26%	12,742	23%
2	UK	1,431	*11%*	1,761	*11%*	1,881	*9%*	5,073	10%	89	*15%*	300	*13%*	332	*10%*	721	11%	5,794	11%
3	Japan	463	*4%*	1,285	*8%*	1,850	*9%*	3,598	7%	103	*17%*	597	*26%*	531	*15%*	1,231	19%	4,829	9%
4	Germany	852	*7%*	535	*3%*	1,360	*7%*	2,747	6%	21	*3%*	73	3%	211	*6%*	305	5%	3,052	6%
5	Sweden	732	*6%*	767	*5%*	637	*3%*	2,136	4%	24	*4%*	75	3%	86	2%	185	3%	2,321	4%
6	Brazil	24	0%	202	*1%*	1,671	*8%*	1,897	4%	4	*1%*	26	1%	307	*9%*	337	5%	2,234	4%
7	Netherlands	399	*3%*	462	*3%*	619	3%	1,480	3%	10	2%	64	3%	82	2%	156	2%	1,636	3%
8	Italy	59	0%	364	*2%*	896	*4%*	1,319	3%	4	1%	54	2%	160	5%	218	3%	1,537	3%
9	Australia	348	*3%*	361	*2%*	512	3%	1,221	3%	12	2%	39	2%	98	3%	149	2%	1,370	2%
10	Turkey	24	0%	195	*1%*	995	*5%*	1,214	2%	1	0%	9	0%	138	4%	148	2%	1,362	2%
11	Canada	323	*2%*	141	*1%*	620	3%	1,084	2%	38	*6%*	117	*5%*	121	4%	276	4%	1,360	2%
12	France	279	*2%*	202	*1%*	332	2%	813	2%	21	*3%*	79	3%	135	4%	235	4%	1,048	2%
13	Finland	269	*2%*	312	*2%*	316	2%	897	2%	21	3%	64	3%	59	2%	144	2%	1,041	2%
14	China	16	0%	64	0%	714	*4%*	794	2%	5	1%	17	1%	205	*6%*	227	4%	1,021	2%
15	Switzerland	128	*1%*	284	*2%*	507	3%	919	2%	10	2%	23	1%	61	2%	94	1%	1,013	2%
16	Israel	236	*2%*	263	*2%*	294	1%	793	2%	15	2%	57	2%	65	2%	137	2%	930	2%
17	Denmark	239	*2%*	229	*1%*	251	1%	719	1%	16	3%	41	2%	32	1%	89	1%	808	1%
18	Norway	260	*2%*	222	*1%*	200	1%	682	1%	7	1%	35	2%	36	1%	78	1%	760	1%
19	Spain	25	0%	157	1%	375	2%	557	1%	1	0%	23	1%	46	1%	70	1%	627	1%
20	South Korea	9	0%	53	0%	413	2%	475	1%	1	0%	16	1%	132	4%	149	2%	624	1%
21	Taiwan	24	0%	126	1%	278	1%	428	1%	1	0%	21	1%	66	2%	88	1%	516	1%
22	Greece	71	*1%*	132	1%	256	1%	459	1%	3	0%	14	1%	38	1%	55	1%	514	1%
23	Belgium	73	*1%*	123	1%	233	1%	429	1%	6	1%	18	1%	51	1%	75	1%	504	1%
24	India	35	0%	71	0%	251	1%	357	1%	2	0%	7	0%	30	1%	39	1%	396	1%
25	South Africa	124	1%	78	1%	55	0%	257	1%	9	1%	14	1%	19	1%	42	1%	299	1%

The sum of italic values in percentage columns represent those that provide c. 70 % of the output in each period

	Period 1986-1988			
	NDOC	%1Q	NIF	CAVG
Medicine, General & Internal	48	21%	1,47	4,68
Anatomy & Morphology	37	30%	0,88	15,78
Pharmacology & Pharmacy	35	34%	0,98	9,03
Surgery	36	21%	0,90	19,44
Radiology, Nuclear Med. & Medical Imaging	30	72%	2,10	30,66
Neuroscience	26	58%	1,07	21,81
Endocrinology & Metabolysm	18	67%	1,24	29,44
Biochemistry & Mol. Biology	18	11%	0,56	10,50
Pathology	17	24%	0,87	15,47
Otorhinolaryngology	16	20%	0,94	7,18

	Period 1996-1998			
	NDOC	%1Q	NIF	CAVG
Materials Science, Biomaterials	166	75%	1,41	17,60
Cellular Biology	162	10%	0,63	14,05
Engineering, Biomedical	143	94%	1,69	19,74
Surgery	141	23%	1,11	13,13
Anatomy & Morphology	142	11%	0,95	13,91
Oncology	108	34%	1,16	19,87
Neuroscience	106	50%	1,09	21,09
Biochemistry & Mol. Biology	103	35%	0,93	24,76
Immunology	103	34%	0,85	20,43
Pathology	82	38%	1,48	14,28

	Period 2006-2008			
	NDOC	%1Q	NIF	CAVG
Engineering, Biomedical	371	35%	1,25	1,52
Surgery	328	17%	0,90	1,16
Materials Science, Biomaterials	312	32%	1,35	1,84
Cellular Biology	232	8%	0,66	1,78
Medicine, General & Internal	187	27%	1,07	3,53
Biochemistry & Mol. Biology	175	35%	0,95	2,31
Oncology	151	23%	0,94	2,83
Medicine, Research & Experimental	124	15%	0,68	0,93
Pharmacology & Pharmacy	122	34%	1,04	2,01
Microbiology	102	37%	1,01	2,142

Fig. 2 The most productive JCR Non-DOSM categories in the three periods studied with their indicators of output and impact (see bibliometric indicators in Table 1)

Figure 4 shows the relations between the specialties (SNA diagram) in the three periods. The six diagrams indicate the interconnection between areas, in DOSM and Non-DOSM.

Discussion

To date, partial analyses of dental-research activity has been published, works in which the output is analysed in a Dentistry specialty or theme [15–17], in a journal or set of them [9, 18] or rather broad geographical analyses [10, 19]. In many such works, MEDLINE has been used to analyse dental-research output but, in general, the WoS is preferred over other databases because it is multidisciplinary (covering all scientific and technological fields), their well-documented quality is guaranteed by peer review [20], and it track citations to calculate an impact factor reflecting use by journals in the JCR [15, 21, 22]. However, in these cases, the analysis of production has always been limited to those published in the DOSM category, and, as observed by Gil et al. [10], "some dental research papers included in other categories of the ISI database may have been missed".

		DOSM					No-DOSM					
		NDOC	%DOC	%1Q	%T3	CAVG	NDOC	%DOC	%1Q	%T3	CAVG	
Period 1986-1988	Endodontics	579	5%	4%	2%	12,11	26	6%	27%	8%	25,31	Endodontics
	General [1]	1721	15%	13%	7%	12,69	61	14%	23%	11%	11,38	General [1]
	Implantology	301	3%	19%	10%	21,01	6	1%	40%	0%	7,00	Implantology
	Materials [2]	1230	11%	17%	10%	13,43	38	8%	32%	13%	13,24	Materials [2]
	Orthodontics [3]	1114	10%	12%	7%	13,30	22	5%	18%	5%	11,41	Orthodontics [3]
	Pathology [4]	469	4%	20%	15%	15,04	42	9%	30%	16%	8,97	Pathology [4]
	Pediatric [5]	729	7%	18%	11%	14,64	29	6%	25%	14%	9,00	Pediatric [5]
	Periodontics	1541	14%	54%	37%	21,96	42	9%	38%	15%	15,25	Periodontics
	Prosthodontics	1689	15%	11%	6%	10,94	36	8%	25%	8%	10,25	Prosthodontics
	Public Health [6]	949	9%	33%	24%	13,74	100	22%	21%	4%	6,03	Public Health [6]
	Radiology [7]	265	2%	13%	8%	13,67	7	2%	17%	0%	7,00	Radiology [7]
	Surgery [8]	539	5%	16%	9%	14,71	41	9%	32%	26%	9,52	Surgery [8]
		NDOC	%DOC	%1Q	%T3	CAVG	NDOC	%DOC	%1Q	%T3	CAVG	
Period 1996-1998	Endodontics	1308	4%	9%	4%	12,92	91	3%	32%	4%	16,89	Endodontics
	General [1]	6153	18%	22%	9%	13,98	569	22%	32%	16%	17,16	General [1]
	Implantology	1535	5%	32%	24%	18,65	91	3%	46%	39%	19,83	Implantology
	Materials [2]	3713	11%	25%	11%	15,94	348	13%	40%	27%	18,59	Materials [2]
	Orthodontics [3]	3413	10%	19%	9%	13,33	226	9%	33%	23%	15,83	Orthodontics [3]
	Pathology [4]	1256	4%	15%	7%	14,14	76	3%	27%	8%	9,92	Pathology [4]
	Pediatric [5]	1895	6%	20%	7%	15,57	130	5%	29%	24%	14,27	Pediatric [5]
	Periodontics	3652	11%	46%	20%	16,19	312	12%	33%	16%	21,20	Periodontics
	Prosthodontics	4569	14%	19%	9%	13,64	312	12%	33%	24%	15,03	Prosthodontics
	Public	2907	9%	29%	13%	13,91	265	10%	30%	16%	17,54	Public Health [6]
	Radiology [7]	1135	3%	17%	10%	13,83	24	1%	21%	13%	8,04	Radiology [7]
	Surgery [8]	2281	7%	28%	15%	14,40	160	6%	26%	13%	14,26	Surgery [8]
		NDOC	%DOC	%1Q	%T3	CAVG	NDOC	%DOC	%1Q	%T3	CAVG	
Period 2006-2008	Endodontics	2321	4%	51%	24%	2,17	349	3%	23%	4%	1,47	Endodontics
	General [1]	10015	18%	26%	8%	1,37	2008	20%	33%	9%	1,69	General [1]
	Implantology	2417	4%	30%	6%	1,35	435	4%	40%	13%	1,62	Implantology
	Materials [2]	7305	13%	33%	10%	1,41	1208	12%	32%	9%	1,70	Materials [2]
	Orthodontics [3]	6439	12%	21%	7%	1,26	922	9%	37%	10%	1,64	Orthodontics [3]
	Pathology [4]	1749	3%	18%	7%	1,49	414	4%	28%	8%	1,88	Pathology [4]
	Pediatric [5]	3344	6%	21%	7%	1,32	611	6%	30%	12%	1,89	Pediatric [5]
	Periodontics	5107	9%	37%	11%	1,55	1009	10%	31%	7%	1,77	Periodontics
	Prosthodontics	7068	13%	24%	8%	1,29	1272	13%	33%	10%	1,66	Prosthodontics
	Public Health [6]	3982	7%	22%	6%	1,36	855	9%	29%	9%	1,99	Public Health [6]
	Radiology [7]	1698	3%	21%	5%	1,46	165	2%	25%	12%	1,31	Radiology [7]
	Surgery [8]	4165	7%	20%	4%	1,34	730	7%	31%	7%	2,08	Surgery [8]

Fig. 3 Dental production by specialties in each period analysed, in DOSM and Non-DOSM, with their indicators of output and impact (see Table 1). (*1*)General Dentistry, (*2*) Dental Materials, (*3*) Orthodontics and Dentofacial Orthopedics, (*4*) Oral and Maxillofacial Pathology, (*5*) Pediatric Dentistry, (*6*) Dental Public Health, (*7*) Oral and Maxillofacial Radiology, (*8*) Oral and Maxillofacial Surgery

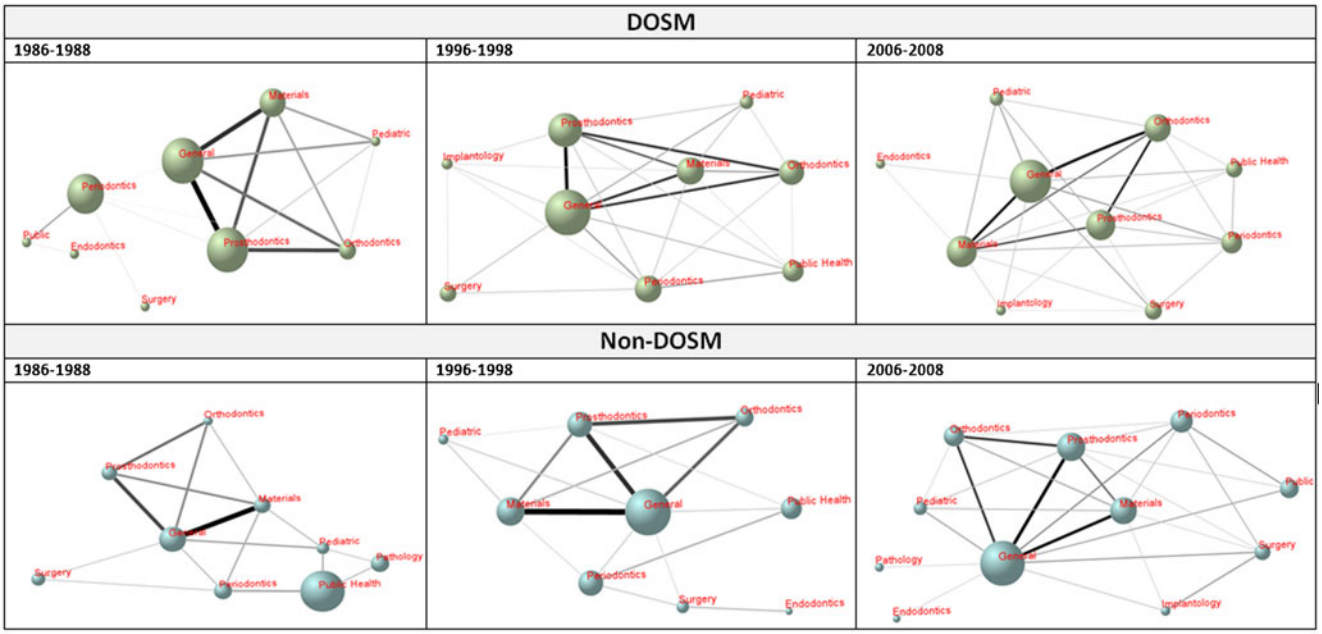

Fig. 4 SNA Diagram DOSM (Dentistry, Oral Surgery and Medicine) and Non-DOSM for the three periods studied. Each *node* in the diagram corresponds to a specialty and its diameter is proportional to the number of documents assigned to it. The *position of each node* is assigned as the relationship with the other nodes. The *thickness of the lines* reflects the documents that share two specialties. Once all the relationships between pairs of nodes in each 3-year period are determined, each diagram shows all 75 relationships calculated for that period

Probably, this has been due to the difficulties posed by recalling this information. Science today is becoming steadily more multidisciplinary, so that a global analysis of scientific output in Dentistry demands the consideration not only of publications in the DOSM but also of journals not included in this category. The present study proposes a specific strategy for the retrieval of this information by providing an overview of world dental scientific output and productivity by specialties and countries over the last three decades and could be used to identify the most productive research lines or the ones with greatest impact. In addition, to analyse publications outside DOSM is useful not only for their quantitative importance (number of articles) but also for their qualitative value, since it enables the identification of themes of interest outside the area and multidisciplinary teams that could have great promise in paradigm shifts. The analysis of this, and of other indicators of collaboration and the influence of institutional funding on the quality of the publications, will be the aim of future studies by our group.

The allocation of papers to subject areas in bibliometrically driven studies is often based simply on journals in which they are published. This approach is not free of criticism [23] and has now effectively been superseded by methods based on analysis also of title words [24, 25], offering a far more accurate classification, with precision and retrieval often exceeding 90 % in some biomedical subfields [26]. In our case, we have designed a mixed strategy combining the thematic search with the institutional one for the recall of the output published in Non-DOSM journals. However, the interpretation of the results of this bibliometric study should take into account a number of potential limitations. The most remarkable that may have affected the search strategy is associated with the selection and the subsequent assignation to specialties of the terms MeSH. The searches may underestimate the actual dental literature in Non-DOSM categories. This is because the key words used are limited to MeSH vocabulary, as opposed to previous bibliometric studies [5, 8] in which, furthermore, multiple free-text searches are used because the specialty being studied in MeSH is not well represented. MEDLINE, being a bibliographic database, normally lags behind the profession in adopting new language. Therefore, the searches, by not being entirely language-inclusive, may have excluded relevant articles [15]. In addition, in the design of a search strategy, there are two options: (1) to make an exhaustive search, which indicates a search strategy that retrieves the largest number of relevant articles but also includes some irrelevant ones or (2) to make a specific search, a selective search strategy, which identifies a small number of the most relevant articles and excludes most irrelevant articles but, unfortunately, also excludes some relevant articles. In the present study, the mixed strategy, both thematic and institutional, ensures the specificity of the searches, while the high numbers of descriptors used, unusual in this type of work, are meant to reach a high percentage of retrieval. Nevertheless, we believe that the possible influence of some of these limitations (if there are any) would remain constant over time and their repercussion in the trend and distribution of

the production would be negligible and thus would not alter the main conclusions of the study.

Our results indicate that the scientific output in dental sciences is growing in number of yearly articles published, in DOSM and Non-DOSM, especially the latter, which sometimes almost quadrupled the DOSM growth rate. Non-DOSM growth could be due either to journal saturation in DOSM submissions, forcing authors to publish in other categories, or to greater multidisciplinarity and collaboration with other branches of science.

Previous studies have suggested that the DOSM category was growing in output [10]. Our data, however, indicate that the greater number of documents is related primarily to the higher absolute number of indexed journals in the database. Figure 1a reflects that the category loses relative weight in Science Citation Index over the study period. This decline, however, was offset by the surge in publications in other Non-DOSM categories, a trend undetected by traditional methodologies based exclusively on the analysis of the DOSM category. Therefore, overall Dentistry research, within and outside DOSM, remained quite stable, in relative terms, over recent decades, although the journals for publication changed.

The number of authors changed markedly in DOSM during the last period, in which a modal value of 1 (in the two foregoing periods) changed to 4 (Fig. 1a). Also, the number of authors gradually rose in Non-DOSM. The co-authorship increase was related to funding, to author productivity [27], to university publication requirements for promotion, and to increased competition for scientific-research grants [9]. Furthermore, collaboration can improve clinical and administrative relationships with other specialties and is needed for long-term follow-up studies [28]. In our case, the higher number of the signatories in Non-DOSM probably resulted from collaboration in other scientific areas, perhaps fomenting publication trends in Non-DOSM journals.

The study of time intervals offers an evolutionary image of Dentistry. The geographic analysis confirmed previous data on the literature for the top-20-ranking countries and for this group incorporating so-called emerging countries [10–19]. This result for dental research is not consistent with findings for research on general biomedical production by Benzer et al. [29] and Rahman and Fukui [30], who observed very little change over time in world rankings, whether based on absolute figures or on production per million inhabitants [10]. Our study reflects that despite the output increase in absolute values between the first and third period in all countries, in relative terms, three trends were differentiated (Fig. 1b): countries with almost stable percentages (e.g. USA, Netherlands, Australia); countries with declining percentages (e.g. UK, Sweden, Denmark, Norway); and countries with rising percentages (e.g. Brazil, Turkey, South Korea, China). The first two groups contain developed countries, and the third emerging countries, except, e.g. Italy and Switzerland (country of generally elite research, which even increased in Dentistry output) or Spain. Notably, Brazil placed fourth in world output during the last period.

Basically, these trends appeared in DOSM and Non-DOSM, although atypical trends occurred, e.g. Germany and Australia, stronger in Non-DOSM. Also, Japan contributed more to Non-DOSM than DOSM, notably in basic sciences (Cell Biology and Molecular Biology) and technology (Engineering and Biomaterials).

Our data reveal a previously undescribed phenomenon: output concentrated in a shrinking number of countries vs. trends in other branches of science [31]. In the first period, 16 countries produced roughly 70 % of the total production in DOSM, while in the last period only 9 countries produced the same percentage (8 and 6 in Non-DOSM, respectively) (Table 3). This is not apparently attributable to greater international collaboration, since, in the two most striking cases of emerging countries that joined the top-20 group (Brazil and Turkey), collaboration reached only 25 % and 16 %, respectively.

In the last 30 years, the JCR categories where dental researchers publish have varied (Fig. 2). In the 1980s, the areas of clinical medicine attracted the most publications, while in the following two decades the most productive and influential areas involved mainly categories in biotechnology and basic medical sciences. This change may reflect the maturation and new challenges in Dentistry practice over the last 20 years, although policy decisions of funding agencies and, perhaps, editorial philosophies of journals may also be the drivers in research and publications. This new perspective has connected disciplines related to the technology of materials and to the study of illness mechanisms in basic medical sciences.

Concerning production by specialties (Fig. 3), the percentages basically stabilized over time, with General Dentistry notably rising and Periodontics decreasing. The latter registered high-impact indices (high %1Q and %T3) in the three periods studied, especially in DOSM, although these percentages progressively diminished.

A striking qualitative jump in Endodontics during the third period was found in DOSM but not in Non-DOSM. Also, Endodontics appears as an isolated specialty in the SNA diagram (Fig. 4). This phenomenon, specific of DOSM, could be because 50 % of the output of this specialty was concentrated in two journals, Journal of Endodontics (J End), and International Endodontic Journal (Int End J), which in the third period were situated among those of the greatest impact of the area. In this period, the number of self-citations of the J End constituted 56 % of the total citations of the journal and 21 % of those of the Int End J, which in turn had 24 % self-citations and 25 % J End. These figures explain the isolation observed of the specialty and, partly, the high-impact factor of both publications.

Implantology showed high impact in the first period, remained steady in the second, and declined in the third in favour of Endodontics in DOSM. Despite the great clinical surge of Implantology, perhaps associated with high scientific productivity, this was not the most productive area, according to our results. Its impact was higher in Non-DOSM than in DOSM. In Non-DOSM the most productive area was General Dentistry, while Implantology had the greatest impact.

Although ideally, biomedical sciences, such as Dentistry, should merge into one discipline, they make up subdisciplines, which sometimes straddle areas of modern medicine that are close but do not overlap, their productivity and scientific impact can be perceived only when viewed as a whole [8]. Generally, output in DOSM and other categories showed notable relations between Dentistry specialties, invariably around a core of General Dentistry, Prosthodontics, Dental Materials, and Orthodontics, this phenomenon being strongest in the first decade of the twenty-first century. The relative isolation of Endodontics (peripheral in the 1980s and the first decade of the new century, disappeared in the 1990s) and Periodontics was notable, as mentioned above, in DOSM and in Non-DOSM over the three periods studied (Fig. 4). Also, the graphs reflect that in the 1990s and the following decade, Implantology was incorporated; Oral and Maxillofacial Pathology and Oral and Maxillofacial Radiology failed to appear in any graph.

The results were surprising, since, given the many journals on Surgery and Periodontics and their excellent positions in DOSM, greater weight (both quantitative and qualitative) might be expected in the context of global Dentistry. Nevertheless, the reasons expressed above on the influence of the exchange of citations in the high-impact indices of Endodontic journals could also explain the relatively marginal positions of these specialties. Also, the weight and the links of Orthodontics and Prosthodontics are striking despite their meagre representation in journals on these DOSM specialties. Thus, to analyse the evolution of an area such as Dentistry based exclusively on the profiles of journals comprising its category of the JCR could generate confusion. The thematic analysis of what is published in the category offers a different picture of what might be deduced from the JCR lists. Thematically, Dentistry has varied little in recent years regarding areas of interest, and the specialties, far from constituting isolated areas of knowledge, are probably becoming more interconnected.

Non-DOSM has evolved similarly, both quantitatively in terms of the weight of the specialties, and in the situation of each specialty in the interrelationships—i.e. the same basic core as in DOSM, with Periodontics and Endodontics in peripheral positions. Nevertheless, it bears emphasising the strength of the link between General Dentistry and Dental Materials, especially in the first and third period. Oral and Maxillofacial Pathology appeared in the 1980s and the first decade of the twenty-first century, while Oral and Maxillofacial Radiology was not present in any period. Dental Public Health appeared in all three periods, in contrast to DOSM, and only in the first decade of the new century did Implantology appear in the graphs.

In summary, this work proposes a new methodology to study the global research activity in Dentistry, not only in the DOSM JCR category. With this new approach, we confirm that in the last three decades, output has been sustained by a growing publication of documents in journals of other categories that also reach high scientific-impact indices. The most productive categories were the areas of clinical medicine in the 1980s, and biotechnology and basic medical sciences areas in the following two decades. Research is concentrated in a steadily smaller number of countries, a previously undescribed phenomenon. Finally, the broad traditional thematic areas, i.e. specialties, of Dentistry have persisted over the last 30 years, with the other subordinate areas.

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