

Bibliometric Analysis of Obstructive Sleep Apnea Research Trends

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Background: This study aimed to describe current trends and areas of future research using a bibliometric evaluation of the publication output associated with research on obstructive sleep apnea (OSA) during the 16-year period of 1991–2006.

Methods: Data encompassing the period from 1991 to 2006 were extracted from the Science Citation Index online version. We analyzed selected documents with “obstructive sleep apnea”, “obstructive apnea”, or “OSA” as a part of the title, abstract, or key words and reported the following parameters: trends of publication output, journal pattern, country of publication, authorship, author-generated key words, and KeyWords Plus®.

Results: The annual number of articles on OSA grew at a faster rate than did the number of general scientific publications, from approximately 200 in 1991 to 650 in 2006. The main subject categories in which research on OSA was conducted were the respiratory system and clinical neurology, each of which accounted for >10% of total articles. Most of the research was conducted in the major industrial countries, with most international collaborations involving the United States and Canada. Certain terms were identified by KeyWords Plus® but not by author-generated key words, and some terms increased in frequency of use over time.

Conclusion: This study provides a bibliometric analysis showing that the annual number of publications related to OSA has been increasing at a much faster rate than the overall scientific literature during the past 16 years in a growing number of specialized journals. Analysis of key words (KeyWords Plus®) suggests research trends and areas for future research. [*J Chin Med Assoc* 2009;72(3):117–123]

Key Words: bibliometric analysis, MEDLINE, obstructive sleep apnea, sleep disorder

Introduction

The quantity and quality of research in the field of sleep has increased rapidly, with a 4-fold rise in the number of publications during the period from 1974 to 2007.¹ Obstructive sleep apnea (OSA) is a sleep-related breathing disorder characterized by repetitive upper airway obstruction, which causes frequent episodes of reduced (hypopnic) or no (apneic) airflow during sleep.² OSA is common in the adult population, with a prevalence of approximately 5%,³ and it may negatively affect multiple organs, resulting in the development of cardiovascular diseases and neurocognitive problems.⁴ OSA can be treated using continuous

positive airway pressure (CPAP), which has been shown to result in improved quality of life.⁵

Bibliometric analysis is a research method used in library and information science to evaluate research performance.^{6,7} This method uses quantitative and statistical analyses to describe patterns of publication on a given topic, in a given field, institute, or country. The increasing use of bibliometric analysis by institutes⁸ and journals⁹ indicates its importance. Close examination of the literature provides information to researchers,¹⁰ and publication output in a certain discipline or topic can represent its previous, current, and future research trends or focus.¹¹ One common method for carrying out bibliometric research is to use the *Science Citation*



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Index (SCI) or *Social Science Citation Index* (SSCI), which are published by the Institute for Scientific Information (ISI), Philadelphia, PA, USA, to trace citations. Numerous medical topics such as sleep research,¹ severe acute respiratory syndrome,¹² respiratory medicine,¹³ patent ductus arteriosus,¹⁴ and asthma research¹⁵ have been analyzed using the SCI and SSCI to assess the performance in each research topic and indicate the authors' impacts on and contributions to their respective fields. However, despite the importance of OSA, there have been no published bibliometric analyses of the research on this disorder. In this investigation, we attempted to gain insights into the quantity and quality of research in the area of OSA by analyzing the SCI database. The results of this study will be of value to researchers in various fields, including clinical neurology, who seek information about the current trends and future directions in sleep-related research.

Methods

Publications containing abstracts were extracted with a literature search performed in August 2007 using the online version of the SCI[®] (<http://scientific.thomson.com/products/sci/>)—ISI Web of Knowledge Service (version 3.1). Author-generated key words, such as “obstructive sleep apnea”, “obstructive apnea”, and “OSA”, and KeyWords Plus[®] were analyzed. KeyWords Plus[®] in the SCI database supplies additional search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes.¹⁶ Data collected from the online searches were extracted and manipulated in Excel spreadsheets to provide the input for the analysis, and the search results were checked to verify that all entries were related to OSA. Documents were analyzed according to trends of publication output, subject category, journal pattern, country of publication, authorship, author-generated key words, and KeyWords Plus[®]. The trend of annual publication output was determined from 1991, the first year in which abstracts were available in ISI, to 2006, the last year for which complete information was available at the time of the search; and the analysis was performed for 4-year periods within this 16-year time span. Articles originating from England, Scotland, Northern Ireland, and Wales were grouped under the United Kingdom (UK) heading. The impact factor of a journal was determined for each document as reported in the *Journal Citation Reports (JCR) 2005*. We determined the type of collaboration for each article by the address of each author, where “independent” was assigned if

no collaboration was found and “international collaboration” was assigned if a paper was co-written by researchers from more than 1 country.

Results

Trends of publication output

There were a total of 6,328 articles in SCI published during the 16 years between 1991 and 2006 with “obstructive sleep apnea”, “obstructive apnea”, or “OSA” in the title. During this time period, the annual number of articles on OSA grew from approximately 200 in 1991 to 650 in 2006 (Table 1). The OSA Productivity Index, which was obtained by dividing the number of articles at each time by the number published in 1991, also grew; and the 3.25-fold increase in the Productivity Index for OSA-related articles over the 16-year period was higher than the 1.81-fold increase in the Productivity Index for all publications obtained from MEDLINE.

Subject category

A wide variety of subjects are related to sleep research. Of the 6,328 articles tabulated, 6,322 had subject category information. Clinical neurology accounted for >10% of all articles and was ranked second, behind the respiratory system, in the listing of subject categories under which research on OSA was conducted (Table 2). However, recently, more publications on OSA have been falling into categories such as pediatrics, and cardiac and cardiovascular systems. In contrast, fewer papers on OSA are being published in categories of more general interest, such as general and internal medicine, and sports sciences.

Journal pattern

Table 3 lists the 7 core journals that published more than 100 papers on OSA research, the corresponding percentage of OSA papers accounted for by each journal over the 16-year period, and impact factor for each journal indexed in the 2005 edition of the *JCR*. The most active journals were *Sleep*, *Chest*, and *American Journal of Respiratory and Critical Care Medicine*. During the period examined, these 3 journals published 8.3%, 7.5%, and 6.2% of the total number of articles, respectively. Among the journals that covered OSA, 94 had an impact factor >10, and these journals published 1.5% of the papers on OSA. Journals that had impact factors ranging from 1 to 2 accounted for 22% of the publications, and 30% of the OSA-related articles were published in journals with an impact factor between 4 and 10.

Table 1. Characteristics of output by year of publication from 1991 to 2006

Year	TP	AU	AU/P	NR	NR/P	PG	PG/P
1991	203	809	4.0	4,474	22	1,151	5.7
1992	238	935	3.9	5,420	23	1,385	5.8
1993	241	969	4.0	5,548	23	1,404	5.8
1994	219	916	4.2	5,661	26	1,386	6.3
1995	341	1,417	4.2	8,454	25	2,103	6.2
1996	349	1,405	4.0	9,099	26	2,171	6.2
1997	291	1,288	4.4	7,671	26	1,977	6.8
1998	324	1,402	4.3	8,654	27	2,219	6.8
1999	378	1,615	4.3	10,029	27	2,527	6.7
2000	474	2,051	4.3	13,737	29	3,106	6.6
2001	405	1,796	4.4	12,086	30	2,682	6.6
2002	435	2,086	4.8	13,836	32	2,932	6.7
2003	587	2,758	4.7	19,023	32	4,088	7.0
2004	576	2,669	4.6	18,518	32	3,844	6.7
2005	594	2,872	4.8	19,661	33	4,152	7.0
2006	673	3,287	4.9	21,275	32	4,552	6.8
Total	6,328	28,275	4.5	183,146	29	41,679	6.6

TP = total number of articles; AU = number of authors; P = publication; NR = cited reference count; PG = page count.

Table 2. Ten ISI subject categories with the most publications

Subject category	1991–2006	1991–1994	1995–1998	1999–2002	2003–2006
	R (TP)	R (TP)	R (TP)	R (TP)	R (TP)
Respiratory system	1 (1,545)	1 (273)	1 (324)	1 (426)	1 (522)
Clinical neurology	2 (1,061)	2 (140)	2 (248)	2 (266)	2 (407)
Otorhinolaryngology	3 (857)	4 (103)	4 (172)	3 (239)	3 (343)
Psychiatry	4 (706)	3 (107)	3 (196)	4 (205)	6 (198)
Physiology	5 (583)	6 (87)	5 (139)	6 (150)	5 (207)
Surgery	6 (481)	8 (55)	9 (81)	7 (117)	4 (228)
General & internal medicine	7 (441)	5 (95)	6 (110)	10 (101)	9 (135)
Critical care medicine	8 (416)	10 (35)	7 (106)	5 (152)	11 (123)
Neurosciences	9 (372)	12 (28)	8 (96)	8 (115)	10 (133)
Pediatrics	10 (371)	9 (50)	11 (65)	9 (102)	7 (154)
Sport sciences	11 (309)	7 (61)	10 (66)	11 (91)	14 (91)
Cardiac & cardiovascular systems	12 (278)	14 (18)	13 (47)	14 (62)	8 (151)
Research & experimental medicine	13 (258)	11 (29)	15 (46)	12 (74)	12 (109)
Dentistry, oral surgery, & medicine	14 (220)	13 (22)	12 (53)	13 (68)	15 (77)
Peripheral vascular disease	15 (205)	16 (13)	16 (35)	15 (61)	13 (96)
Anesthesiology	16 (131)	15 (17)	19 (15)	17 (34)	16 (65)
Endocrinology & metabolism	17 (111)	19 (10)	20 (12)	16 (35)	17 (54)

R = ranking; TP = total publications.

Table 3. Seven core journals publishing the most obstructive sleep apnea research articles

Journal	TP	%	IF
<i>Sleep</i>	524	8.3	4.95
<i>Chest</i>	477	7.5	4.008
<i>American Journal of Respiratory and Critical Care Medicine</i>	395	6.2	8.689
<i>Journal of Applied Physiology</i>	276	4.4	3.037
<i>Laryngoscope</i>	174	2.7	1.617
<i>Otolaryngology-Head and Neck Surgery</i>	147	2.3	1.218

TP = total publications; IF = impact factor.

Table 4. Rank and proportion of articles on obstructive sleep apnea for the top 11 countries

Country	SP	SP%	CP	CP%	RP	RP%	TP	TP%
USA	2,251	40	337	56	2,125	38	2,588	41
Canada	411	7.2	114	19	366	6.6	525	8.3
Germany	398	7.0	93	15	416	7.5	491	7.8
France	365	6.4	72	12	354	6.4	437	6.9
Japan	362	6.4	57	9.4	375	6.8	419	6.7
UK	254	4.5	84	14	232	4.2	338	5.4
Australia	216	3.8	68	11	187	3.4	284	4.5
Spain	165	2.9	31	5.1	161	2.9	196	3.1
Sweden	145	2.5	43	7.1	154	2.8	188	3.0
Italy	153	2.7	32	5.3	157	2.8	185	2.9
Israel	126	2.2	24	4.0	124	2.2	150	2.4

SP = independent publications; SP% = percent of independent publication output for 1 country; CP = international collaborative publications; CP% = percent of international collaboration publication output for 1 country; RP = corresponding author publications; RP% = percent of corresponding author publications output for 1 country; TP = total publications; TP% = percent of total publications output for 1 country.

Table 5. Top 16 most frequently used author-generated key words from 1991 to 2006 and in each of the 4-year periods

Authors' key word	1991–2006	1991–2006	1991–1994	1995–1998	1999–2002	2003–2006
	TP	R (%)	R (%)	R (%)	R (%)	R (%)
Obstructive sleep apnea	801	1 (19)	2 (15)	2 (15)	1 (19)	1 (29)
Sleep apnea	796	2 (19)	1 (27)	1 (15)	2 (18)	2 (25)
Snoring	321	3 (7.6)	3 (11)	3 (7.2)	3 (7.9)	5 (8.2)
Polysomnography	282	4 (6.7)	7 (5.6)	6 (5.3)	4 (7.8)	3 (9.1)
Sleep	281	5 (6.6)	5 (6.9)	4 (6.6)	6 (6.2)	4 (8.7)
Obstructive sleep apnea syndrome	230	6 (5.4)	12 (3.7)	8 (3.5)	5 (6.9)	7 (8)
Obesity	210	7 (5)	6 (5.8)	12 (2.6)	7 (5.1)	5 (8.2)
Sleep apnea syndrome	208	8 (4.9)	4 (9.5)	5 (6)	8 (4.7)	13 (3.7)
Hypertension	183	9 (4.3)	9 (5.1)	7 (5)	9 (3.8)	10 (5)
Continuous positive airway pressure	150	10 (3.5)	17 (2.1)	16 (2)	10 (3.6)	8 (6.5)
Sleep-disordered breathing	141	12 (3.3)	29 (1.4)	19 (1.7)	11 (3.5)	9 (6.3)
Apnea	128	13 (3)	11 (3.9)	13 (2.5)	14 (3)	12 (4)
Hypoxia	109	14 (2.6)	17 (2.1)	16 (2)	13 (3.2)	16 (3.4)
Blood pressure	102	15 (2.4)	13 (3.5)	9 (2.9)	16 (2.1)	23 (2.5)
Sleep disorders	101	16 (2.4)	45 (0.93)	10 (2.8)	15 (2.7)	17 (2.9)
Upper airway	100	17 (2.4)	10 (4.6)	16 (2)	17 (2)	17 (2.9)

TP = total publications; R = ranking.

Distribution of research among countries

Table 4 shows the ranking for the top 11 countries in terms of output for the 6,296 OSA-related publications that provided addresses for authors. The major industrial countries ranked highest, with the United States first producing 41% of the papers, and Canada second with 7.2%. The United States and Canada also produced the greatest number of papers that were determined to be international collaborations by author addresses.

Authorship

The average number of authors per article was 4.5 from 1991 to 2006. The 6,328 published articles were authored by 15,084 authors, among which 11,011

(73%) contributed just 1 article, 1,998 (13%) authored 2 articles, 767 (5.1%) authored 3 articles, 385 (2.6%) authored 4 articles, and 223 (1.5%) authored 5 articles.

Author-generated key words and KeyWords Plus®

Table 5 summarizes the most frequently used author-generated key words. A total of 6,413 key words were listed by authors in the 4,233 articles with records of author-generated key words in the *SCI* database. Most of the key words (73%) were used just once, and 11% were used twice. Table 6 shows the distribution of key words obtained from KeyWords Plus®. The ranking of most terms identified by KeyWords Plus® is similar to that for the key words determined by the authors.

Table 6. Top 22 most frequently used key words from KeyWords Plus® during 1991 to 2006 and in each of the 4-year periods

KeyWords Plus®	1991–2006	1991–2006	1991–1994	1995–1998	1999–2002	2003–2006
	TP	R (%)	R (%)	R (%)	R (%)	R (%)
Obstructive sleep apnea	1,360	1 (23)	1 (16)	1 (19)	1 (24)	1 (27)
Positive airway pressure	706	2 (12)	6 (7.2)	3 (9.1)	2 (11)	2 (15)
Sleep apnea	593	3 (10)	2 (12)	2 (11)	3 (11)	4 (8.2)
Hypertension	461	4 (7.8)	15 (4.1)	6 (6.7)	4 (8.6)	3 (9)
Apnea syndrome	359	5 (6.1)	4 (8.6)	4 (7.4)	9 (5.7)	17 (4.8)
Apnea	357	6 (6)	3 (8.9)	5 (7.2)	13 (5.4)	16 (4.9)
Pressure	353	7 (6)	7 (6.4)	6 (6.7)	6 (6.6)	15 (5)
Daytime sleepiness	351	8 (5.9)	14 (4.3)	12 (5.4)	5 (6.7)	9 (6.2)
Prevalence	340	9 (5.7)	13 (4.5)	13 (5)	12 (5.5)	7 (6.6)
Blood pressure	335	10 (5.7)	30 (3)	10 (5.8)	10 (5.7)	8 (6.4)
Children	314	11 (5.3)	23 (3.4)	16 (4.4)	8 (5.8)	10 (6)
Therapy	313	12 (5.3)	17 (3.9)	17 (4.2)	7 (6.5)	11 (5.5)
Uvulopalatopharyngoplasty	296	13 (5)	8 (6.2)	8 (6.3)	10 (5.7)	22 (3.5)
Men	295	14 (5)	5 (7.7)	9 (6.1)	14 (5.1)	23 (3.4)
Association	294	15 (5)	45 (2)	39 (2.1)	16 (4.5)	5 (7.7)
Disease	289	16 (4.9)	9 (5.6)	19 (3.9)	17 (4.4)	11 (5.5)
Adults	281	17 (4.7)	79 (1.2)	35 (2.2)	15 (4.8)	6 (7.1)
Disorders	254	18 (4.3)	25 (3.3)	21 (3.7)	21 (3.9)	13 (5.2)
Population	248	19 (4.2)	35 (2.7)	23 (3.6)	20 (4)	14 (5.1)
Hypoxia	242	20 (4.1)	10 (5.1)	11 (5.4)	19 (4.1)	27 (3)
Humans	227	21 (3.8)	10 (5.1)	14 (4.7)	18 (4.2)	33 (2.7)
Mortality	226	22 (3.8)	12 (4.8)	14 (4.7)	21 (3.9)	29 (3)

TP = total publications; R = ranking.

However, KeyWords Plus® identified additional terms among the top 15, such as “daytime sleepiness”, “children”, “therapy”, and “men” that were not apparent among the authors’ key words.

Terms that relate specifically to the field of clinical neurology, such as “sympathetic nervous system” and “stroke”, are shown in Table 7. The analysis in Table 7 also shows that some terms, for example “stroke”, have risen in rank over time, with an increase from the overall ranking of 55 to 40 for the period 2003–2006.

Discussion

This study provides a bibliometric analysis showing that the annual number of publications related to OSA has been growing at a much faster rate than the overall scientific literature during the past 16 years. This study was limited because only publications that were contained and ranked within SCI were analyzed. Nevertheless, our results for the specific area of OSA are consistent with those obtained from a similar analysis of the literature of sleep science in general, which reported a 4-fold increase in the productivity index for sleep-related publications compared to a 2-fold increase in that for all scientific publications over the

period from 1974 to 2004.¹ This growth may reflect the increasing awareness of the importance of sleep in modern society^{17,18} and the rapid rise in the number of sleep centers and laboratories that can diagnose sleep disorders.¹⁹

This analysis of OSA-related publications has revealed a trend toward specialization in the area of OSA-related research. For example, a decrease in the number of publications was noted in subject areas such as general and internal medicine, psychiatry, and sports sciences. Furthermore, among the 7 core journals that published the most OSA-related research, the highest ranking (*Sleep*) focuses exclusively on sleep research. The wide variety of subject categories that contained publications on OSA also reflects the impact of OSA on many aspects of health, including the respiratory, cardiovascular, and nervous systems.

The subject category of clinical neurology ranked second in terms of the number of publications related to OSA. This suggests that OSA is a research area of increasing concern to neurologists. Within the category of clinical neurology, the current focus of OSA research is indicated by the terms “autonomic nervous system”, “quality of life”, “depression”, “serotonin”, “stroke”, and “epilepsy”. From the perspective of frequency of use of key words, it is apparent that the

Table 7. Additional terms and frequency of use (rank) over time as analyzed by KeyWords Plus®

KeyWords Plus®	1991–2006	1991–2006	1991–1994	1995–1998	1999–2002	2003–2006
	TP	R (%)	R (%)	R (%)	R (%)	R (%)
Sympathetic nervous system	55	27 (1.3)	29 (1.4)	21 (1.6)	26 (1.4)	54 (1.3)
Quality of life	50	31 (1.2)	#N/A	81 (0.43)	32 (1.2)	22 (2.6)
Autonomic nervous system	40	40 (0.94)	62 (0.69)	34 (0.86)	44 (0.95)	46 (1.4)
Depression	34	48 (0.8)	#N/A	81 (0.43)	49 (0.86)	40 (1.6)
Stroke	32	55 (0.76)	203 (0.23)	139 (0.26)	58 (0.78)	40 (1.6)
Sudden infant death syndrome	30	63 (0.71)	29 (1.4)	56 (0.6)	113 (0.43)	69 (1)
Epilepsy	24	83 (0.57)	203 (0.23)	81 (0.43)	196 (0.26)	54 (1.3)
Serotonin	23	88 (0.54)	45 (0.93)	65 (0.52)	113 (0.43)	103 (0.68)
Oxidative stress	16	122 (0.38)	#N/A	#N/A	#N/A	46 (1.4)
Metabolic syndrome	15	132 (0.35)	#N/A	#N/A	#N/A	54 (1.3)
Adiponectin	6	363 (0.14)	#N/A	#N/A	#N/A	139 (0.51)
Brain natriuretic peptide	6	363 (0.14)	#N/A	#N/A	#N/A	139 (0.51)
C-reactive protein	6	363 (0.14)	#N/A	#N/A	#N/A	139 (0.51)
Randomized trial	6	363 (0.14)	#N/A	#N/A	#N/A	139 (0.51)
Atrial fibrillation	5	443 (0.12)	#N/A	#N/A	#N/A	159 (0.43)
Hypothalamus	5	443 (0.12)	#N/A	#N/A	#N/A	159 (0.43)
Laparoscopic	5	443 (0.12)	#N/A	#N/A	#N/A	159 (0.43)
Spatial learning	5	443 (0.12)	#N/A	#N/A	#N/A	159 (0.43)

TP = total publications; R = ranking.

relationship between OSA and other areas of neurologic disease requires continued investigation.

The results of our analysis of the distribution of research among different countries indicated that the majority of research on OSA is being conducted in the major industrialized countries. This is probably because sleep research in general has enjoyed considerable attention and support in these countries and the study of OSA usually requires a rather resource-intensive overnight observation for diagnosis and monitoring.

Our study found a large number of key words that were used only once. This, combined with the variety of subject categories noted, may indicate a lack of continuity in research and a wide disparity in research focuses corresponding to the increasing significance of OSA in multiple disciplines.²⁰

A unique aspect of this study was the use of the KeyWords Plus® feature to identify research trends.²¹ Previous bibliometric studies have used only author-generated key words, but we have analyzed with the use of KeyWords Plus® simultaneously. In general, the source title and author-generated key words supply reasonable details about an article's subject.²² KeyWords Plus®, however, can reveal greater detail about an article's content.²³ Thus, by combining the terms from KeyWords Plus®, it is possible to glimpse more details about the subject of each individual article and to identify emerging themes within the field. The term metabolic syndrome illustrates this. Our data showed that the area of metabolic syndrome ranked 132 in the

overall period of study, but that its rank rose to 54 in the most recent period of 2003 to 2006. This suggests that recognition of the association between OSA and metabolic syndrome has emerged since 2003.²⁴ Therefore, articles that may not have identified OSA as a key word but may be part of a developing research trend will be captured in a bibliometric analysis using KeyWords Plus®.

Terms that were identified by KeyWords Plus®, for example “daytime sleepiness”, “children”, and “men” may confirm that most patients with OSA experience daytime sleepiness,²⁵ that sleep disorders are important in children as well as adults,²² and that men are more likely to have OSA than women. The most commonly used key words after “OSA” and “sleep apnea” were “snoring” and “polysomnography”. From this observation, we might infer that current OSA research is focused on clinical symptoms, such as snoring, and frequently used methods of diagnosis, such as polysomnography. On the other hand, there is less emphasis on basic laboratory research about OSA at present. These terms may suggest areas where additional research is needed in the future.

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