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Posterior Instrumentation of Cervical Spine: A Bibliometric Analysis of Trends in Publication

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Abstract

Aim The aim of this study was to perform a bibliometric analysis of the articles published on posterior instrumentation of cervical spine and to study the general publishing trends over the years in this topic in terms of journals, authors, topics, keywords, collaborating countries, etc.

Material and Methods Articles were searched on the web of science using appropriate keywords. A bibliometric analysis was performed using Bibliometrix R package

Results A total of 1,953 studies were identified between 1991 and 2023 including 1,782 articles and 171 reviews from 198 sources. A total of 3,421 author's keywords were used by 6,725 authors. Thirty-four documents are single authored. The average co-author per document is 5.63. The average citation per document is 22.62. There is international co-authorship in 13.11% documents. RM Xu and Sonntag VKH have maximum publications ($n = 28$). The "Spine" journal has the maximum number of publications ($n = 335$) and best H index of 64. United States has maximum number of publications ($n = 1,720$) and citations ($n = 19,573$). Publication by Harms et al in the "Spine" in 2001 has the highest global ($n = 956$) & local ($n = 272$) citations. Three-dimensional printing and atlantoaxial fixation are emerging trends.

Conclusion The findings of this study enhance the knowledge on the topic of posterior instrumentation of cervical spine and shall guide the trends and directions of future research and innovation.

Keywords
- cervical spine
- posterior instrumentation
- pedicle screw fixation
- lateral mass fixation
- bibliometric analysis

Introduction

Mankind has been trying to understand and treat spinal pathologies since the beginning of human civilization. Earliest description of cervical spine fractures and its treatment are found in the Babylonian papyrus (1550 BC).[1] The first recorded evidence of cervical spine surgeries being performed is in the Hammurabi's code of law ((1955–1912 BC).[2] As understanding of the anatomy of cervical spine increased, there were attempts of surgeries for cervical spine. Both the anterior and posterior approach were being practiced. The first description of posterior cervical spine surgery was given by Hadra in 1891.[3] Anterior approaches to the neck were developed for other conditions needing exposure of oropharynx, buccal cavity, retropharyngeal space, etc.[4–6]

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There was an underlying fear of going anteriorly where many vital structures came in the way. Hence, posterior approach was favored by many surgeons due to the familiar anatomy and absence of any neuro vascular structure in the field. The initial results were poor due to instability arising from lack of bone grafting techniques and weak implants. Improved results were reported in the 1950s with use of bone grafting.[7] Only indication for cervical spine surgery in earlier days was treatment of complications of Pott's disease but some contemporary surgeons extended the indications to cervical spine fractures, instabilities and tumors as well.[4,8] Gradually, surgeons moved away from posterior approach surgeries to the anterior approach surgeries in the late 1950s as it did not compromise the posterior stabilizing structures of the cervical spine.[9–11] The interest in the posterior approach was renewed in the 1970s after the Japanese introduced various forms of laminotomies to overcome the instabilities arising from earlier posterior surgeries involving laminectomies.[12–14] There is greater acceptability of posterior instrumentation of cervical spine among surgeons worldwide that was helped by the availability of strong implants like pedicle screws, hooks, etc. and development of novel surgical techniques like lateral mass fixation.[15,16] Concurrent developments in the field of microscopy and widespread availability of computed tomography scan and magnetic resonance imaging further increased the accuracy of surgeons performing posterior instrumentation in the cervical spine.[17,18] Recent advancement in the field of three-dimensional (3D) printing has made it possible to safely plan and operate upon the pediatric cervical spine and fixation of atlanto-axial vertebrae.[19,20]

There has been a lot of literature being published on posterior instrumentation of cervical spine. The rate and volume of publication have increased rapidly in recent times and it is not possible for individuals to be updated with the latest developments in the field. Hence, there is a chance of missing a critical development or relevant information. Literature reviews become important in this respect to effectively analyze the data already published in scientific literature and provide an evidence-based insight for the researchers to upgrade his professional judgement and expertise.[21] Among various qualitative and quantitative approaches available for performing literature reviews, bibliometrics provides an objective and a reliable analysis. It does a statistical measurement of the science, scientist, and scientific activity.[22] The overall process is complex and requires an extensive knowledge of programming skills among the researchers to be able to employ the steps involved in data analysis and visualization necessary for bibliometric analysis. It is made easy by the availability of automated workflow software and tools.[23]

This study aims to perform a bibliometric analysis of all the articles published on the topic of posterior instrumentation of cervical spine and to study the general publishing trends over the years in this topic in terms of journals, authors, topics, keywords, collaborating countries, etc.

Table 1 Inclusion and exclusion criteria for data extraction

Inclusion criteria	Exclusion criteria
Original articles & review articles with key words "cervical," "surgery," "posterior instrumentation," "pedicle screw fixation," "lateral mass fixation"	Letter to editors, notes, conference papers
Language—English	
Year—1991 to 2022	

Material and Methodology

Data Extraction

The published data on posterior instrumentation of cervical spine was extracted from "Web of Science (WOS)" for the analysis.[24] We included articles published in English language only. Only the original and review articles were included in the data extraction and analysis, while editorials, letter to editors, conference presentations, and commentaries were excluded from the list. The query was designed to look for all the available articles included the terms "cervical spine," "surgery," "posterior instrumentation," "pedicle screw fixation," and "lateral mass fixation" with appropriate Boolean operators as applicable (►**Table 1**).

Data Analysis

The available data from WOS was extracted in plaintext format and was analyzed using the Bibliometrix R package (University of Naples Federico II, Naples, Italy).[25] The data thus generated had information regarding authors, document type, journals, number of cited references, titles of the studies, total number of citations, year of publication, affiliation of the authors, corresponding authors, keywords, etc. Bibliometric analysis was done using performance mapping and science mapping.[26]

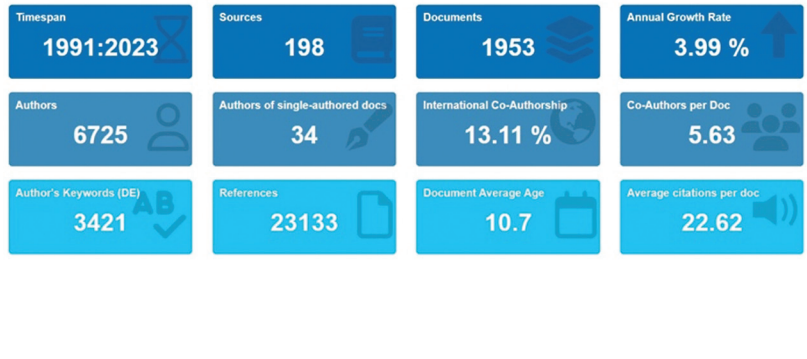
Results

Generic Attributes of the Dataset

After applying the inclusion and exclusion criteria, a total of 1,953 documents were found on the topic in WOS, published between 1991 and 2023. The annual growth rate for the publications was 3.99%. The average age of the documents was 10.7 years. There were a total of 1,782 articles and 171 reviews published in 198 journals. A total of 3,421 author's keywords and 23,133 references were used. The average citations per document came to 22.62 (►**Fig. 1**).

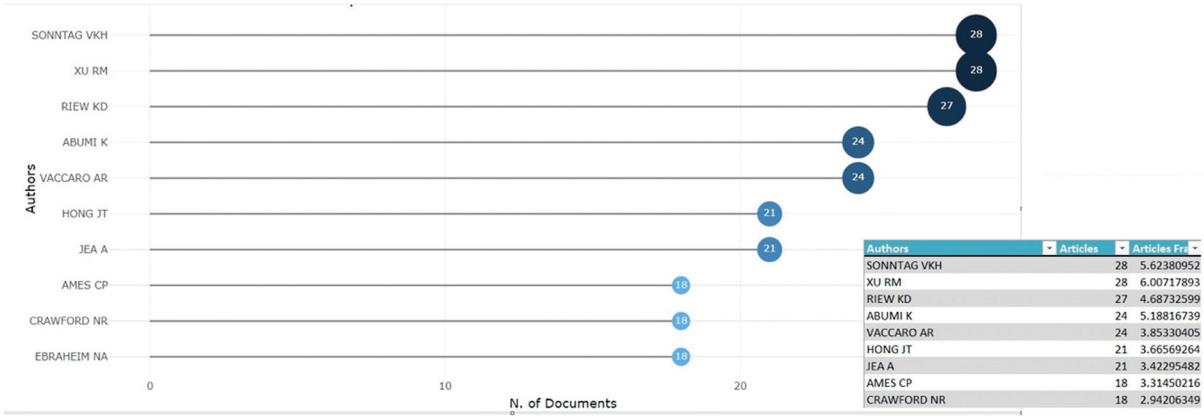
Analysis of Authors

A total of 6,725 authors wrote all the included studies. Only 34 of them had written one or more articles independently and the rest collaborated either locally or internationally for writing articles. The average number of co-authors per document was 5.63. The international co-authorship was found in 13.11% of the articles (►**Fig. 1**). Sonntag VKH and Xu RM were the most relevant author with the maximum



Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1991:2023
Sources (Journals, Books, etc)	198
Documents	1953
Annual Growth Rate %	3.99
Document Average Age	10.7
Average citations per doc	22.62
References	23133
DOCUMENT CONTENTS	
Keywords Plus (ID)	2194
Author's Keywords (DE)	3421
AUTHORS	
Authors	6725
Authors of single-authored docs	34
AUTHORS COLLABORATION	
Single-authored docs	40
Co-Authors per Doc	5.63
International co-authorships %	13.11
DOCUMENT TYPES	
article	1782
review	171

Fig. 1 Main information.



Authors	Articles	Articles Fra
SONNTAG VKH	28	5.62380952
XU RM	28	6.00717893
RIEW KD	27	4.68732599
ABUMI K	24	5.18816739
VACCARO AR	24	3.85330405
HONG JT	21	3.66569264
JEA A	21	3.42295482
AMES CP	18	3.31450216
CRAWFORD NR	18	2.94206349

Fig. 2 Most relevant authors.

number of articles published ($n = 28$) followed by Riew KD ($n = 27$; ►**Fig. 2**). While Sonntag VKH published his first article in 1991 and has last publication in 2019 & Xu RM had his first publication in 1995 and his last publication came in 2018, Riew KD started publishing in 1998 and has a recent publication even in 2023 (►**Fig. 3**). Abumi K (h index= 17, g index= 24, m index = 0.68), Sonntag VKH (h index= 17, g index= 28 and m index= 0.515), and Vaccaro AR (h index= 17, g index= 24, m index = 0.629) had the highest impact in terms of "h-index" followed by Riew KD (h index= 15, g index= 26, m index = 0.6) (►**Fig. 4**). In terms of local citations Abumi K ($n = 717$), Ito M ($n = 470$) and Xu RM ($n = 465$) were the top three authors (►**Fig. 5**). The graph based on "Lotka's law" shows that majority of the authors ($n = 4972$, 73.9%) have contributed to a single article only, while the number of authors who have contributed to five or more articles is very low ($n = 320$, 4.75%) (►**Fig. 6**). The authors collaboration network showed a total of 11 clusters. In terms of number of collaborating authors, cluster 3 (maximum collaboration between Vaccaro AR and Hillbrand AS and Xu RM and Ebrahiem NA), cluster 5 (maximum collaboration between Imagama S and Fujibayashi S), cluster 6 (maximum collaboration between Riew KD and Lee SH), and cluster 10 (maximum collaboration between Ames CP and Theodore N) are the largest (►**Fig. 7**). The "3 plot graph" shows that most of the top 10 authors were from United States and majority of them were associated with Barrow neurological institute, Arizona, United States (►**Fig. 8**).

Analysis of Journals

The "Spine" journal ($n = 335$; h index = 64, g index= 103, m index= 1.93, TC = 14580) has been the leader in terms of h-index, number of articles published, and total citations. The "European spine journal" ($n = 188$; h index = 38, g index= 46, m index= 1.52, TC = 4862) is the distant second in the list (►**Fig. 9**). The "Spine" started publishing on cervical spine in 1991 and has been the leading journal since then in terms of number of articles published. "World Neurosurgery" is the latest in the top 10 list of journals and started publishing in 2009 and has shown a rapid increase in the number of articles published (►**Fig. 10**). The "Spine" ($n = 16494$), "European Spine Journal," ($n = 3576$) and "Journal of Neurosurgery" ($n = 3451$) are the top three journals in terms of citations by the articles included for the bibliometric analysis (►**Fig. 11**). Three journals namely "Spine," "European Spine Journal," and "Journal of Neurosurgery—Spine" were

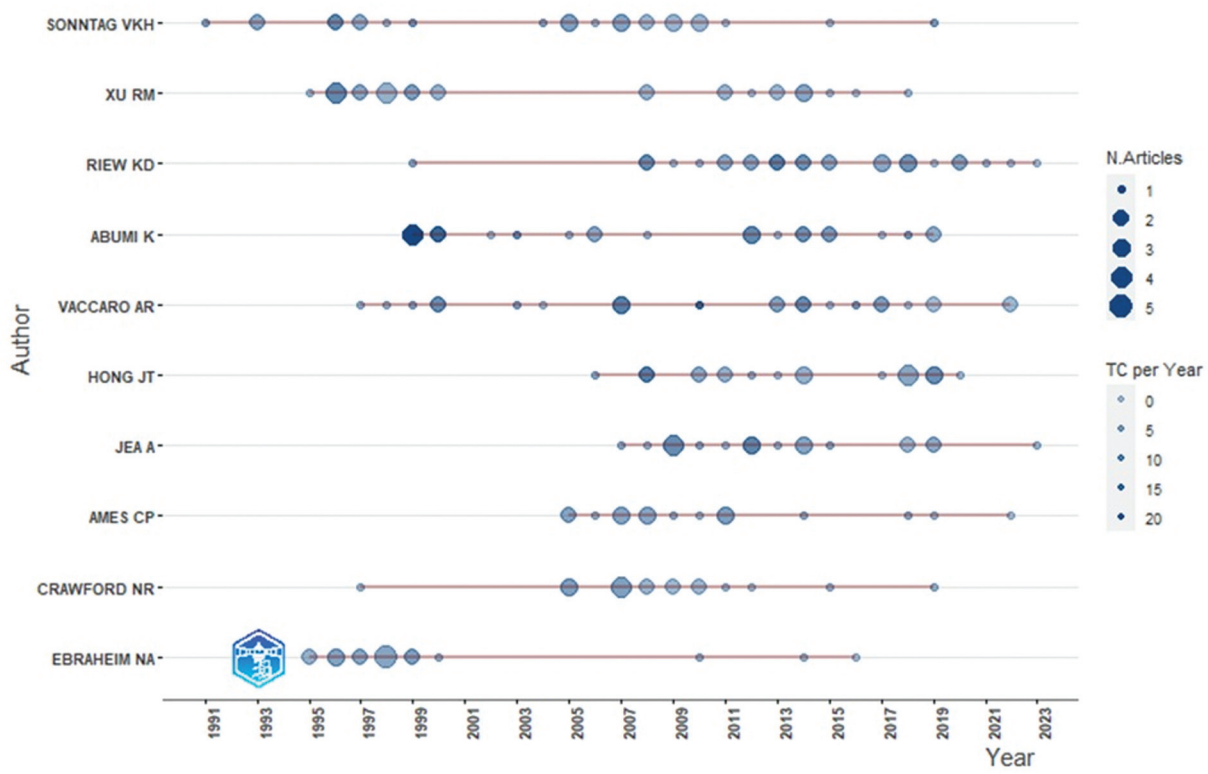
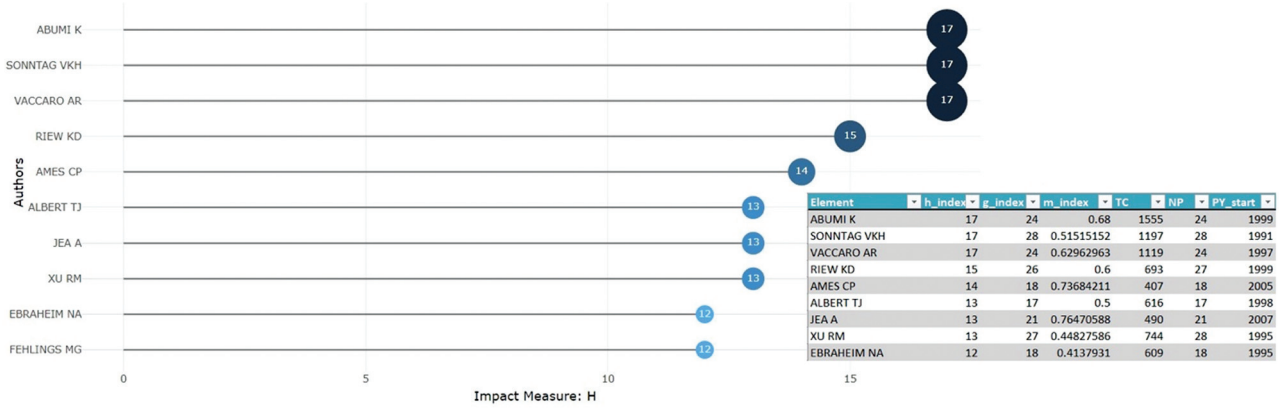


Fig. 3 Authors production over time.



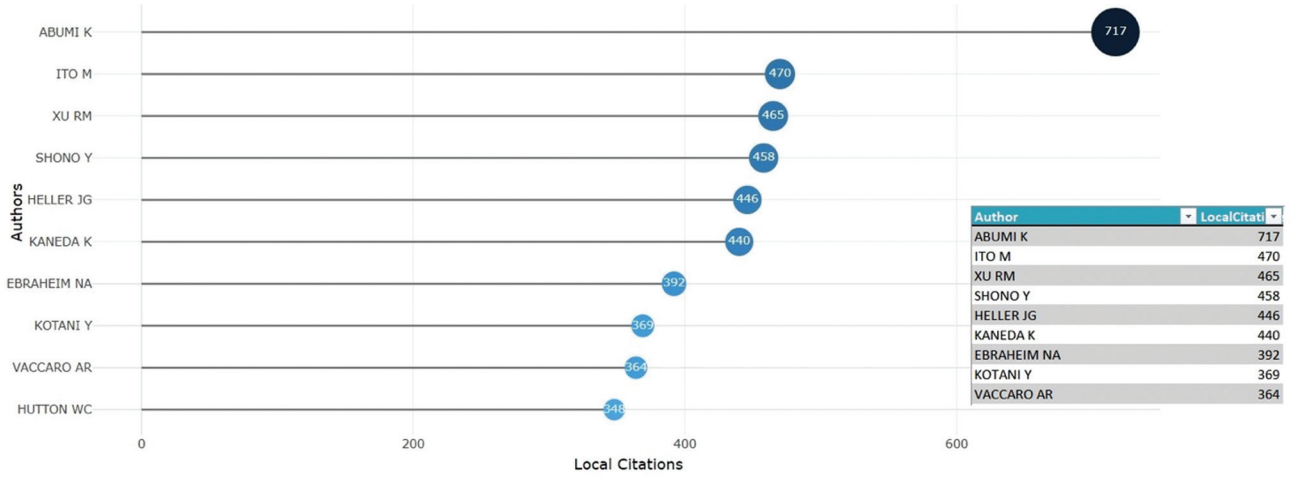
Element	h_index	g_index	m_index	TC	NP	PY_start
ABUMI K	17	24	0.68	1555	24	1999
SONNTAG VKH	17	28	0.51515152	1197	28	1991
VACCARO AR	17	24	0.62962963	1119	24	1997
RIEW KD	15	26	0.6	693	27	1999
AMES CP	14	18	0.73684211	407	18	2005
ALBERT TJ	13	17	0.5	616	17	1998
JEA A	13	21	0.76470588	490	21	2007
XU RM	13	27	0.44827586	744	28	1995
EBRAHEIM NA	12	18	0.4137931	609	18	1995

Fig. 4 Author local impact.

identified as the major contributors of articles on posterior instrumentation of the cervical spine as per "Bradford's Law" (►**Fig. 12**).

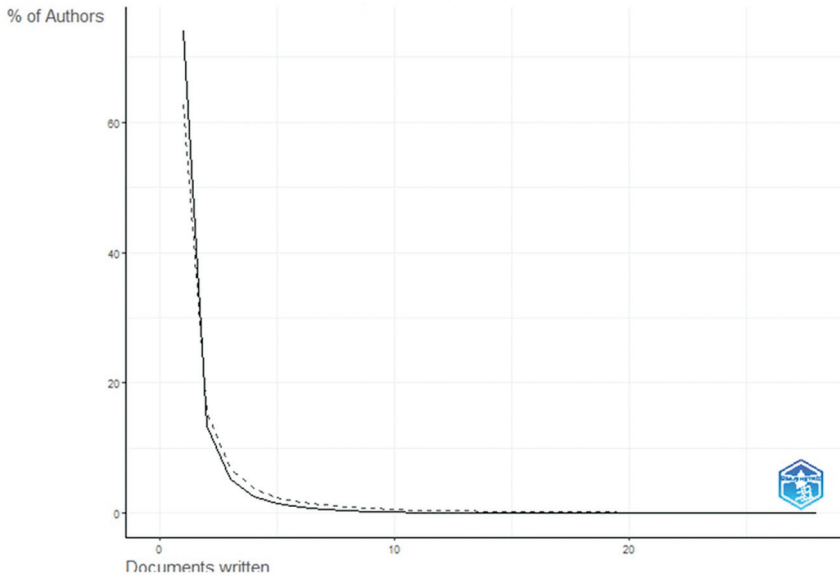
Analysis of Relevant Countries

United States ($n = 1720$), China ($n = 708$), and Japan ($n = 500$) are the top three countries in term of number of publications (►**Fig. 13**). In terms of international collaboration among authors, United States ($n = 692$, single-country publication [SCP] = 597, multi-country publication [MCP] = 95), China ($n = 361$, SCP= 331, MCP = 30) and Japan ($n = 211$, SCP= 204, MCP= 7) are the top three countries. Canada (MCP ratio= 0.348), Switzerland (MCP ratio= 0.238), Germany (MCP ratio= 0.214), and Korea (MCP ratio= 0.172) ranked highest, among the top 10 countries, in terms of fraction of total publication involving authors from multiple countries (►**Fig. 14**). The authors from United States collaborated mainly with authors from China, Korea, Germany, and Canada. Similarly, authors from China collaborated with authors from Korea, Denmark, Germany, Greece, and India in most of their articles. Indian authors have very little collaboration with international authors compared with



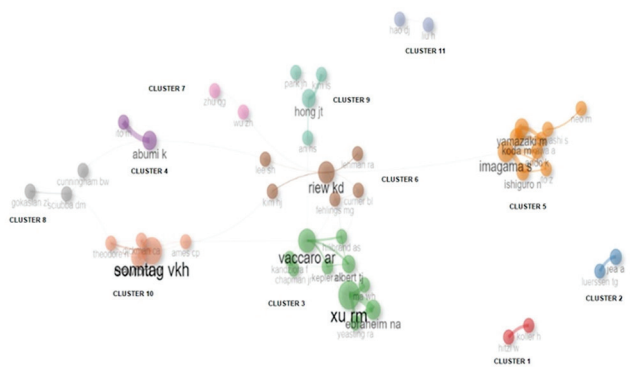
Author	LocalCitati
ABUMI K	717
ITO M	470
XU RM	465
SHONO Y	458
HELLER JG	446
KANEDA K	440
EBRAHEIM NA	392
KOTANI Y	369
VACCARO AR	364

Fig. 5 Most local cited author.



N.Articles	N.Authors	Freq
1	4972	0.739330855
2	900	0.133828996
3	353	0.052490706
4	180	0.026765799
5	102	0.015167286
6	62	0.009219331
7	44	0.006542751
8	34	0.005055762
9	18	0.00267658
10	19	0.002825279
11	9	0.00133829
12	6	0.000892193
13	5	0.000743494
14	3	0.000446097
15	4	0.000594796
16	2	0.000297398
17	2	0.000297398
18	3	0.000446097
21	2	0.000297398
24	2	0.000297398
27	1	0.000148699
28	2	0.000297398

Fig. 6 Lotka's law.



Node	Cluster	Betweenn	Closeness
koller h	1	0	1
hitzl w	1	0	1
jea a	2	0	1
luerssen tg	2	0	1
xu rm	3	68.1242695	0.00645161
vaccaro ar	3	257.267105	0.00884956
ebraheim na	3	0.15384615	0.00520833
albert tj	3	92.4338888	0.00806452
ma wh	3	6.72188437	0.00641026
kepler ck	3	54.7110764	0.00819672
hillibrand as	3	227.234581	0.00925926
yeasting ra	3	0	0.00518135
kandziora f	3	0	0.00684932
chapman jr	3	0	0.00684932
abumi k	4	95.7342854	0.00641026
ito m	4	0	0.00512821
imagama s	5	261.871212	0.008
yamazaki m	5	0	0.00628931
koda m	5	0	0.00628931
fujibayashi s	5	39	0.00632911
ishiguro n	5	0	0.00617284
ando k	5	4.12878788	0.00636943
neo m	5	0	0.00507614
okawa a	5	0	0.00628931
ito z	5	0	0.00617284

Node	Cluster	Betweenn	Closeness
riew kd	6	445.710531	0.00980392
fehlings mg	6	13.049611	0.00877193
kim hj	6	72.7857143	0.00819672
currier bl	6	0	0.00793651
lee sh	6	114.734285	0.00769231
lehman ra	6	0	0.0070922
zhu qg	7	0	0.00561798
wu zh	7	39	0.00719424
sciubba dm	8	58.4990119	0.00531915
gokaslan zl	8	0	0.00440529
cunningham bw	8	43.2332972	0.00549451
hong jt	9	76	0.00552486
park jh	9	0	0.00456621
an hs	9	111	0.00684932
kim is	9	0	0.00456621
sonntag vkh	10	42.7594288	0.00680272
ames cp	10	168.075184	0.00833333
crawford nr	10	24.4339593	0.00680272
dickman ca	10	4.07232655	0.00680272
theodore n	10	55.2657146	0.00578035
hao dj	11	0	1
liu h	11	0	1

Fig. 7 Author collaboration network.

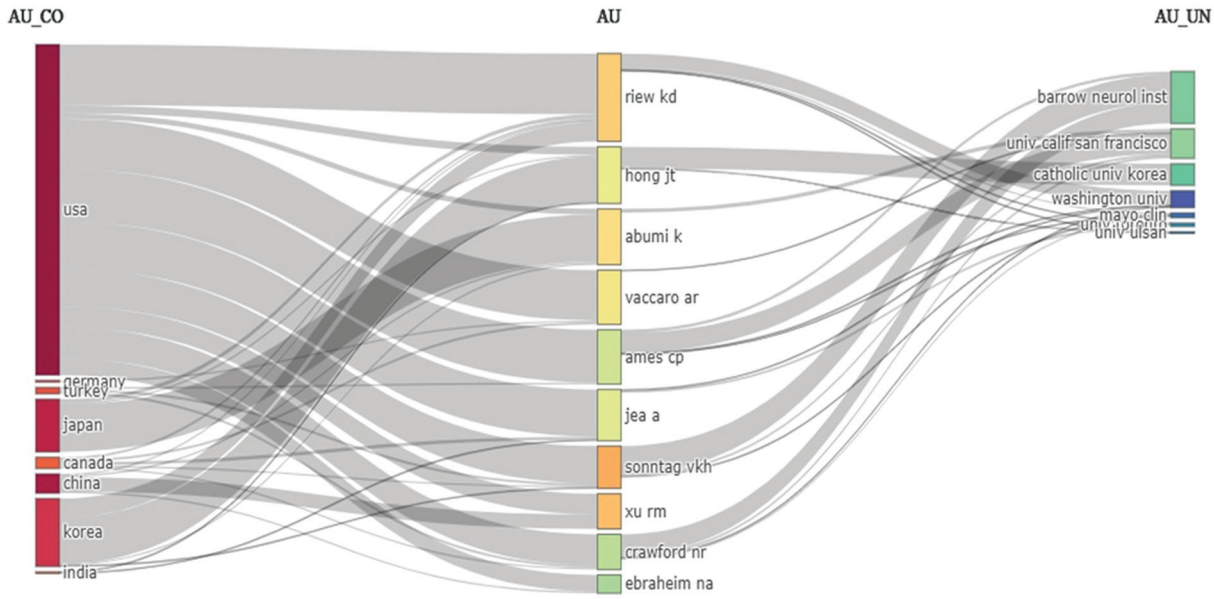
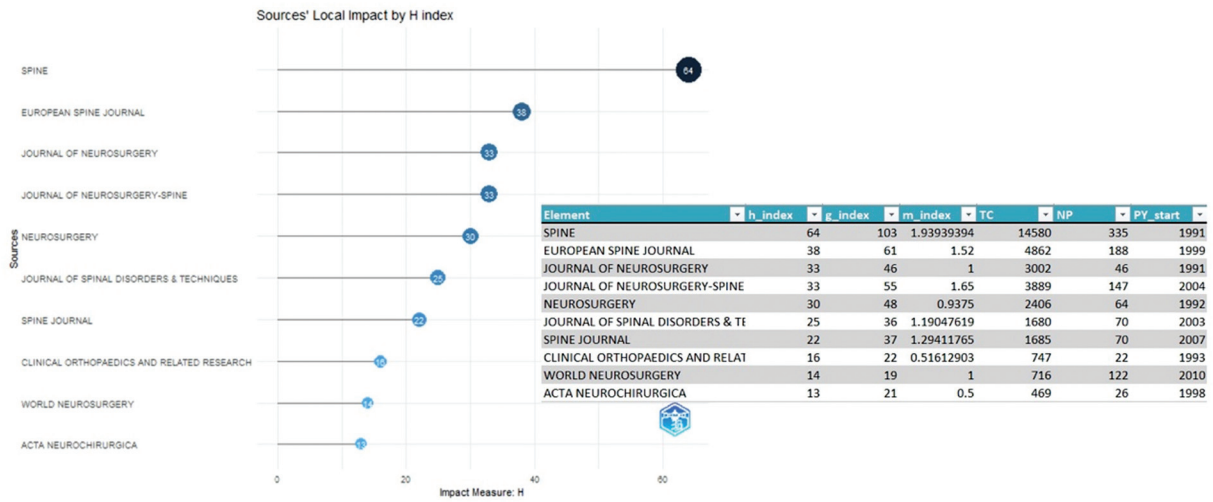


Fig. 8 Three plot graph—country, author, affiliation.



Element	h_index	g_index	m_index	TC	NP	PY_start
SPINE	64	103	1.93939394	14580	335	1991
EUROPEAN SPINE JOURNAL	38	61	1.52	4862	188	1999
JOURNAL OF NEUROSURGERY	33	46	1	3002	46	1991
JOURNAL OF NEUROSURGERY-SPINE	33	55	1.65	3889	147	2004
NEUROSURGERY	30	48	0.9375	2406	64	1992
JOURNAL OF SPINAL DISORDERS & TE	25	36	1.19047619	1680	70	2003
SPINE JOURNAL	22	37	1.29411765	1685	70	2007
CLINICAL ORTHOPAEDICS AND RELAT	16	22	0.51612903	747	22	1993
WORLD NEUROSURGERY	14	19	1	716	122	2010
ACTA NEUROCHIRURGICA	13	21	0.5	469	26	1998

Fig. 9 Source local impact.

authors from other countries. They mainly collaborate with authors from United Kingdom, Indonesia, and Iraq (►**Fig. 15**). United States ($n = 19573$, average citation per document $= 28.3$), Japan ($n = 5222$, average citation per document $= 24.7$), and China ($n = 3975$, average citation per document $= 11$) are the top three countries in term of citations of their articles (►**Fig. 16**).

Analysis of Affiliations

The University of California, San Francisco ($n = 52$) followed by Barrow Neurological Institute, Arizona, United States ($n = 47$) and Catholic University of Korea, Seoul ($n = 41$) were the top three universities based on the number of publications on the relevant topics (►**Fig. 17**). Barrow Neurological Institute, Arizona, United States, and University of Iowa, United States started research and publication on the topic much before 1991. University of California, San Francisco, started their journey in the field in 2003 but has quickly surpassed all the institutes in terms of number of articles published (►**Fig. 18**).

Analysis of Documents

A total of 1953 articles were included in the study. The most commonly used author's keywords were "cervical spine" ($n = 440$), "pedicle screw" ($n = 152$), and "biomechanics" ($n = 119$) (►**Fig. 19**). The co-word analysis showed three cluster of descriptors, cluster 1 was dominated by keyword like "fixation," "spine," and "complication," while cluster 2 was dominated by the keywords "anterior," "decompression," "plate fixation," and "follow up" and the main keywords in cluster 3 were "fusion," "cervical spine," "stabilization." and "instrumentation" (►**Fig. 20**). The article by J Harms et al (DOI —10.1097/00007632-200111150-00014, Spine, 2001) had the

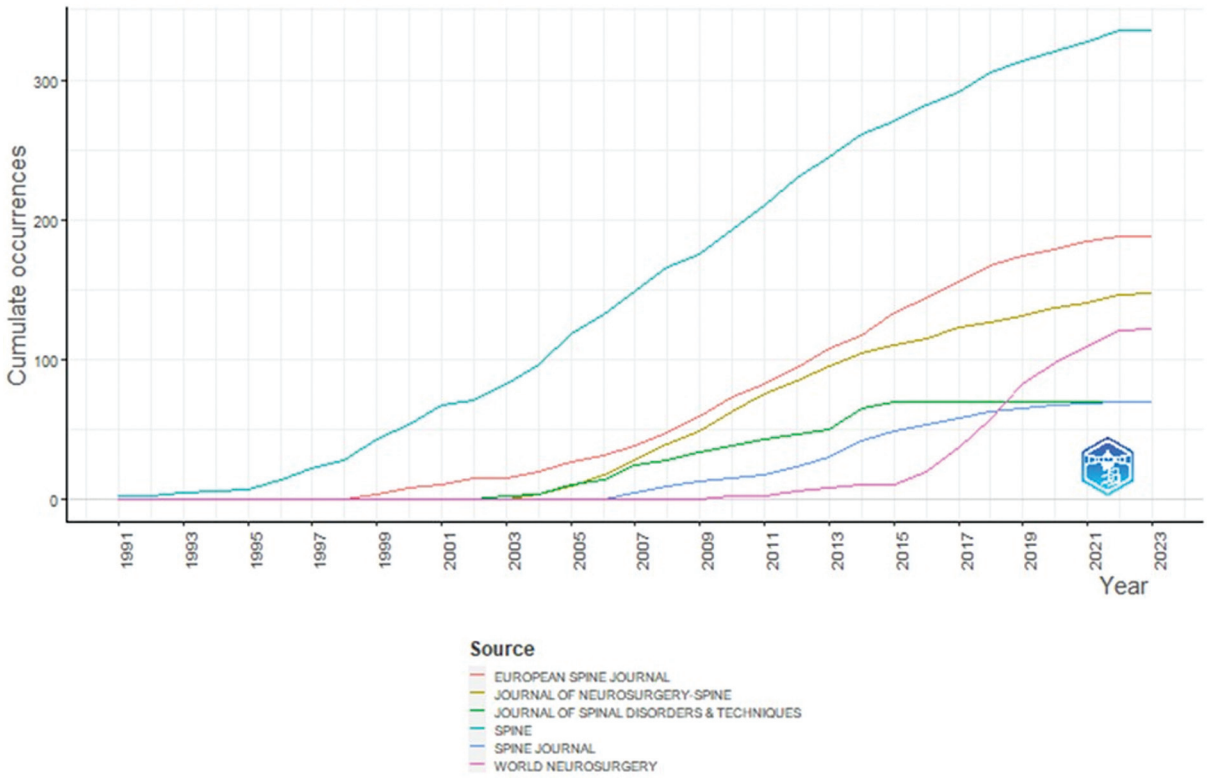


Fig. 10 Source production over time.

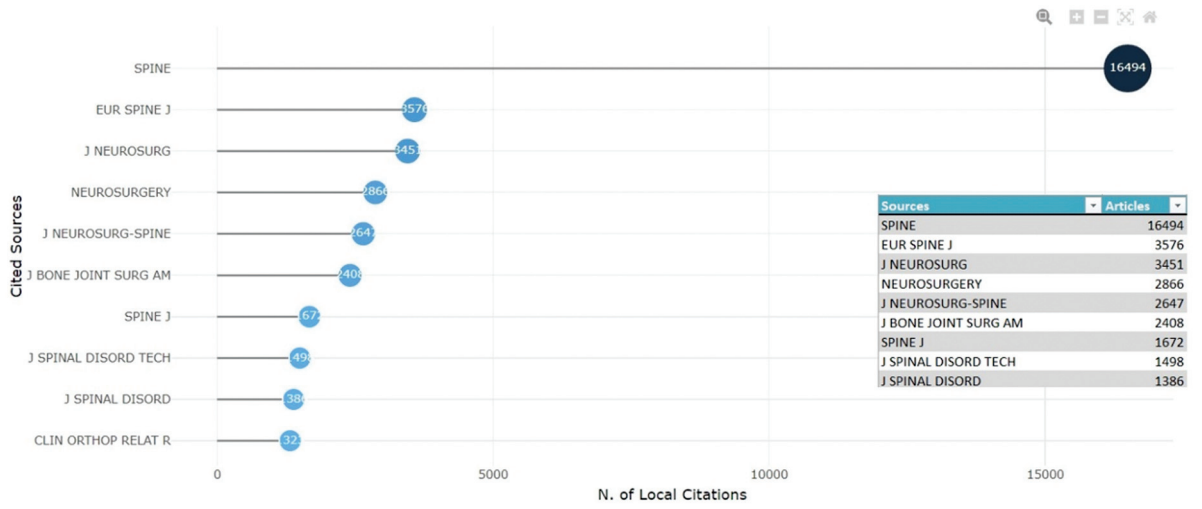


Fig. 11 Most local cited source.

highest number of citations by authors worldwide (total citations= 956, total citations per year = 41.56) followed by article by ID Gelalis et al (DOI—10.1007/s00586-0110201103, European Spine Journal, 2012) (total citations= 395, total citations per year = 32.91) and K Abumi et al (DOI—10.1097/00007632-200004150-00011, Spine, 2000) (total citations= 341, total citations per year = 14.2) (►**Fig. 21**). In terms of citation within the articles being analyzed, J Harms et al (DOI—10.1097/00007632-200111150-00014, Spine, 2001) ($n = 272$) and EL Jones et al (DOI—10.1097/00007632-199705010-00009, Spine, 1997) ($n = 240$) topped the table (►**Fig. 22**). The analysis of co-citation network of the contributing authors shows two clusters. Cluster 1 was formed with the article by Abumi K et al (DOI: 10.1097/00007632-199907150-00007, Spine, 1999) as the reference article and the cluster 2 was formed with the article by Wright NM et al (DOI—10.3171/foc.1998.4.2.2, Journal of Neurosurgery, 1998) as the reference article (►**Fig. 23**). The historical analysis shows two cluster of articles being published. Cluster 1 consists of articles published earlier and deal with pedicle screw

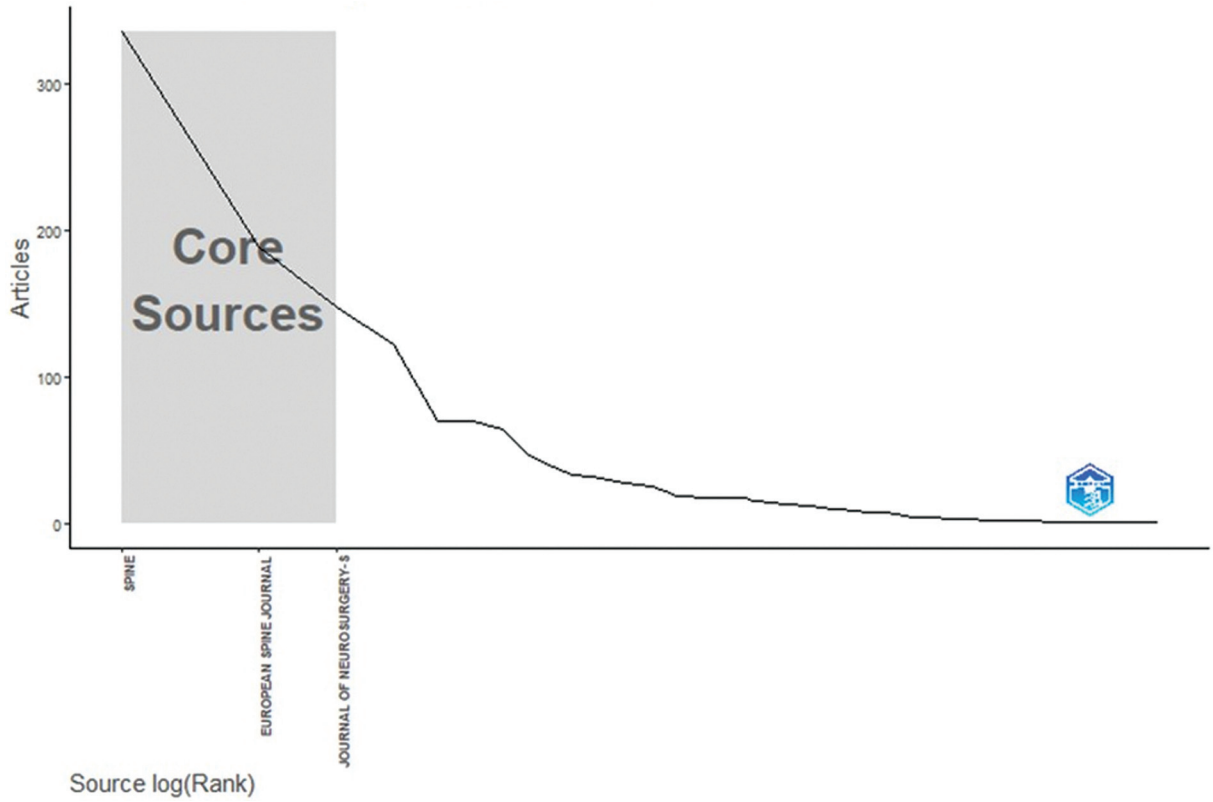


Fig. 12 Bradford law.

region	Freq
USA	1720
CHINA	708
JAPAN	500
SOUTH KOREA	307
GERMANY	296
TURKEY	150
CANADA	135
INDIA	100
FRANCE	97

Fig. 13 Country's scientific production.

fixation and lateral mass fixation for cervical spine, while cluster 2 consists of articles published in recent time and they deal with more complicated procedures like atlanto axial fixation (►**Fig. 24**).

Analysis of Emerging Trends

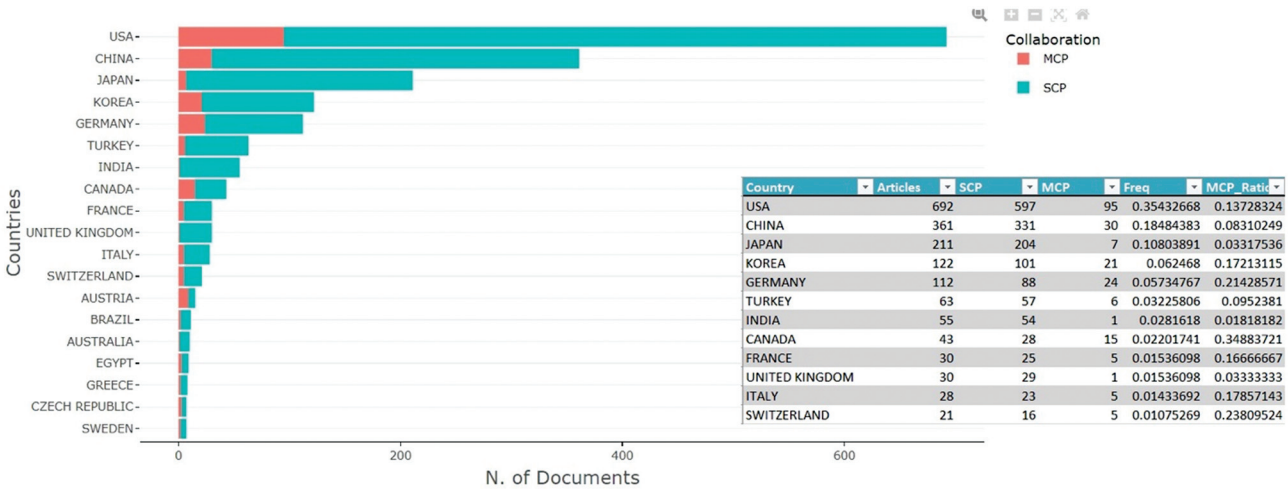
The thematic map shows that the basic themes of research over the years have been focusing on anatomy and lesions of cervical spine, decompression of the cervical spine, and cervical spine fixation and fusion techniques, but the research in recent times is focused more on the accuracy of insertion and placement of screws in the lateral mass, pedicles or interbody fusion, use of CT scan, and atlanto axial fixation (►**Fig. 25**). The analysis of the trend topics using author's keywords and the parameter set to a minimum word frequency = 5 and number of words per year = 1, we find the keywords "nerve root injury" (1998), "spinal stabilization" (1999), transpedicular screw (2000) and animal model (2006) appear in early period denoting the focus of research on development of techniques of pedicle screw fixation for cervical spine stabilization. The author's keywords found in recent times are atlantoaxial dislocation (2016), subaxial cervical spine (2018), 3D printing (2019), and paravertebral foramen screw (2022) indicating a shift in focus of research more on accessing the upper cervical spine as the techniques for middle and lower level cervical surgery have been perfected by the research over the years (►**Fig. 26**).

Conceptual Structure

The factorial analysis of the author's keywords using multivariate correspondence analysis shows the keywords "spine," "cervical," "cervicothoracic junction," "lateral mass screw," "spinal instrumentation," "spinal fusion," and "surgery" contribute maximally to the articles selected for the analysis, while the keywords like "atlantoaxial instability" and "vertebral artery" contribute the least (►**Fig. 27**).

Discussion

Posterior instrumentation of cervical spine has been favored by spine surgeons across the globe since early days. There has



Country	Articles	SCP	MCP	Freq	MCP_Ratio
USA	692	597	95	0.35432668	0.13728324
CHINA	361	331	30	0.18484383	0.08310249
JAPAN	211	204	7	0.10803891	0.03317536
KOREA	122	101	21	0.062468	0.17213115
GERMANY	112	88	24	0.05734767	0.21428571
TURKEY	63	57	6	0.03225806	0.0952381
INDIA	55	54	1	0.0281618	0.01818182
CANADA	43	28	15	0.02201741	0.34883721
FRANCE	30	25	5	0.01536098	0.16666667
UNITED KINGDOM	30	29	1	0.01536098	0.03333333
ITALY	28	23	5	0.01433692	0.17857143
SWITZERLAND	21	16	5	0.01075269	0.23809524

Fig. 14 Top 10 countries based on multicountry publication (MCP) and single-country publication (SCP).

From	To	Frequency
USA	CHINA	32
USA	KOREA	32
USA	GERMANY	24
USA	CANADA	23
USA	JAPAN	14
USA	UNITED KING	11
USA	TURKEY	9
USA	AUSTRIA	7
USA	SWITZERLANI	7
USA	EGYPT	5
USA	GREECE	5
USA	ITALY	5
USA	THAILAND	5

From	To	Frequency
JAPAN	KOREA	4
JAPAN	CANADA	2
JAPAN	GERMANY	2
JAPAN	AUSTRIA	1
JAPAN	INDONESIA	1
JAPAN	UGANDA	1

From	To	Frequency
UNITED KINGDOM	AUSTRIA	4
UNITED KINGDOM	CZECH REPUB	3
UNITED KINGDOM	AUSTRALIA	1
UNITED KINGDOM	HUNGARY	1

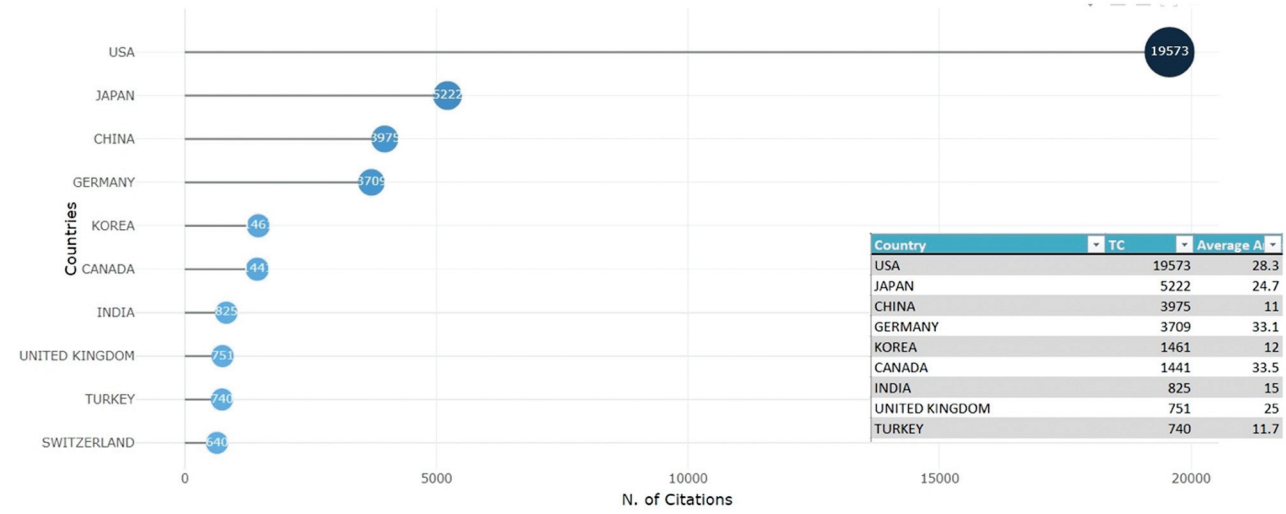
From	To	Frequency
FRANCE	ITALY	3
FRANCE	SAUDI ARABIA	2
FRANCE	SWEDEN	2
FRANCE	SWITZERLANI	2
FRANCE	ARGENTINA	1
FRANCE	BRAZIL	1
FRANCE	FINLAND	1
FRANCE	HUNGARY	1
FRANCE	LEBANON	1

From	To	Frequency
INDIA	UNITED KING	2
INDIA	INDONESIA	1
INDIA	IRAQ	1

From	To	Frequency
CHINA	KOREA	5
CHINA	DENMARK	1
CHINA	GERMANY	1
CHINA	GREECE	1
CHINA	INDIA	1
CHINA	ITALY	1
CHINA	JAPAN	1
CHINA	NETHERLAND	1
CHINA	UNITED KING	1

From	To	Frequency
KOREA	EGYPT	2
KOREA	INDIA	2
KOREA	INDONESIA	2
KOREA	UNITED KING	2
KOREA	TURKEY	1

Fig. 15 Country's collaboration network.



Country	TC	Average A
USA	19573	28.3
JAPAN	5222	24.7
CHINA	3975	11
GERMANY	3709	33.1
KOREA	1461	12
CANADA	1441	33.5
INDIA	825	15
UNITED KINGDOM	751	25
TURKEY	740	11.7

Fig. 16 Most cited country.

been a rapid advancement in the field with improvement in the quality of implants and development of novel tools and techniques for fixation. The development of high-resolution imaging modalities and availability of intraoperative imaging and navigation tools for assistance during surgery have increased our accuracy in terms of implant placement and have improved surgical outcomes in terms of final reduction achieved and decreased complication rates. There is a large amount of literature available on the topic ($n = 1953$ for WOS, $n = 2105$ for PubMed and $n = 2928$ for Scopus) that needs the help of software for detailed data analysis and obtaining qualitative and quantitative.

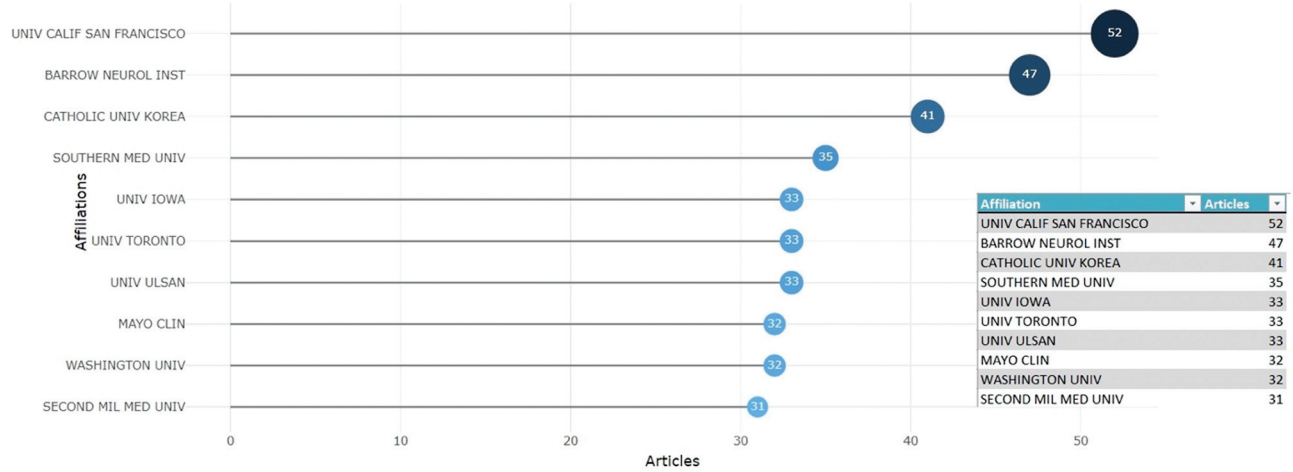


Fig. 17 Most relevant affiliation.

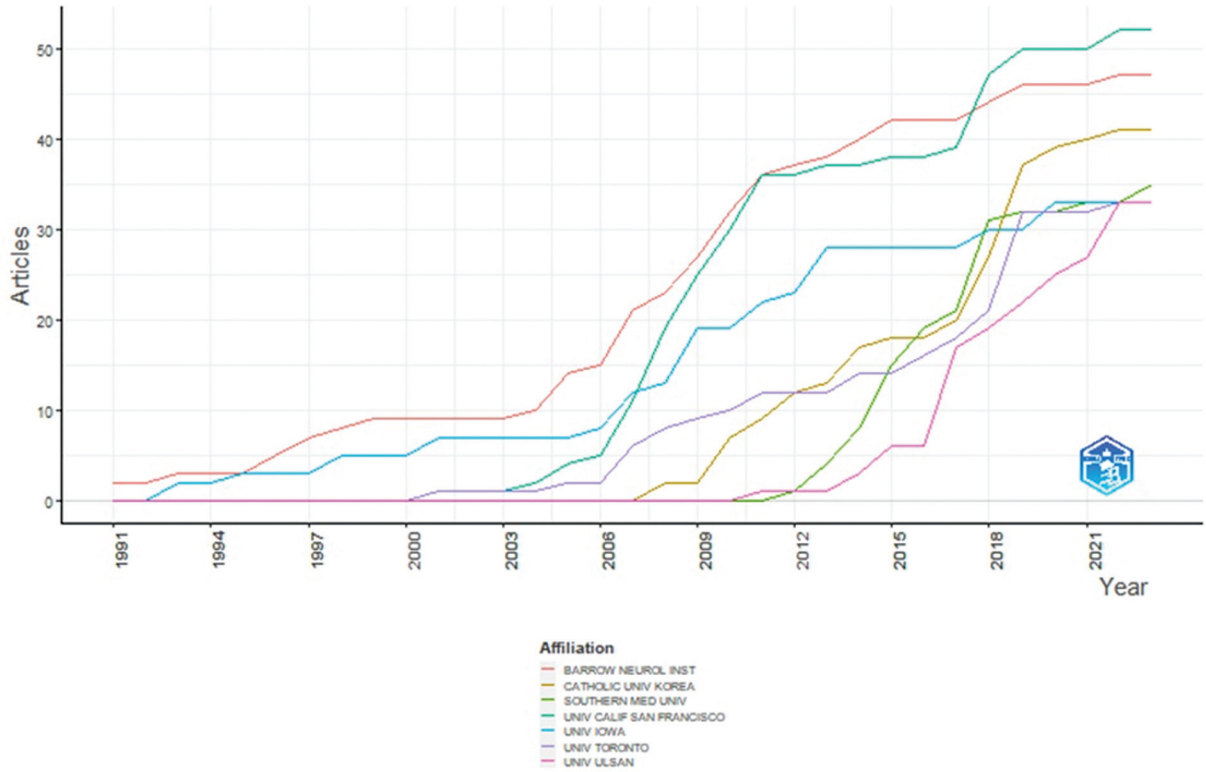
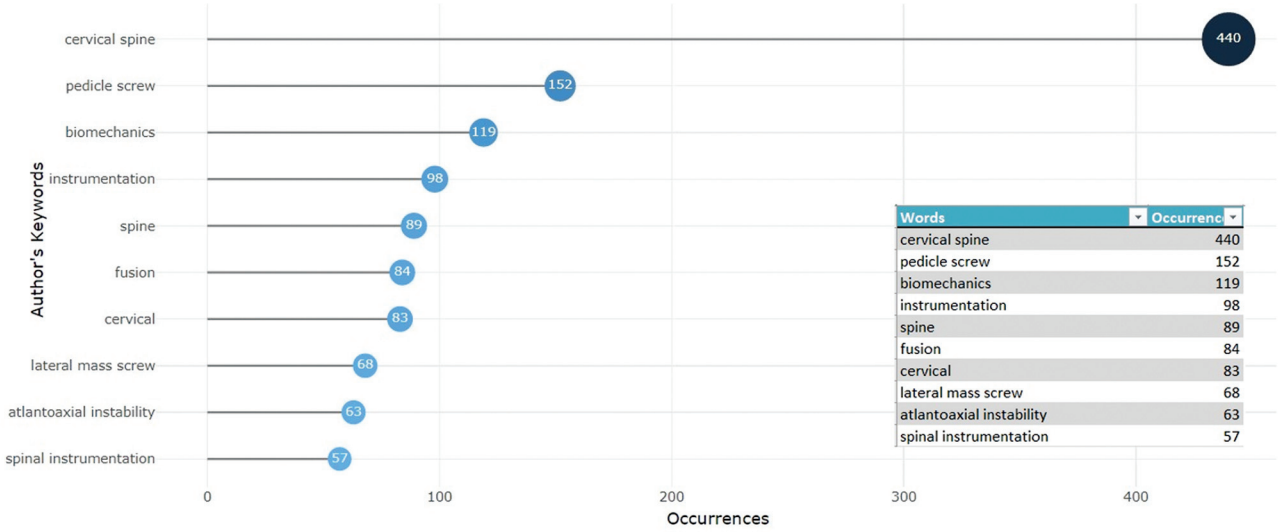


Fig. 18 Affiliation production over time.

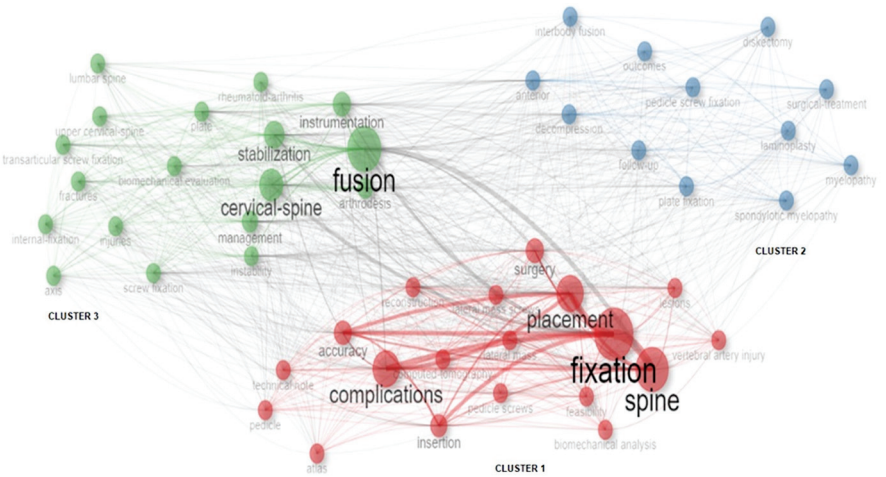
We have used WOS for obtaining relevant data because it is one of the earliest and largest citation index platform and the metadata provided in this platform is complete in terms of authors, type of documents, journals, citations, keywords, and references sourced across multiple databases. The data available from PubMed and Scopus is not complete (►**Fig. 28**).

It is evident that the annual scientific production in terms of articles published has been rising steadily since 1991. There were only six articles published in 1991 and the number rose to 132 in the year 2017 (highest for any given year till date). There have been 111 articles published in 2022 and the year 2023 has already has 21 publications till May (►**Fig. 29**). The average citations per year rose from 1991 upto 2001 but has seen gradual decline after that because of the exponential increase in the annual article production rate (►**Fig. 30**). The "Bradford law" was proposed in 1948. It states that "if we arrange the journals in decreasing order of article productivity on a given subject, then we may divide them into a nucleus of journals more



Words	Occurrenc
cervical spine	440
pedicle screw	152
biomechanics	119
instrumentation	98
spine	89
fusion	84
cervical	83
lateral mass screw	68
atlantoaxial instability	63
spinal instrumentation	57

Fig. 19 Author's keywords.

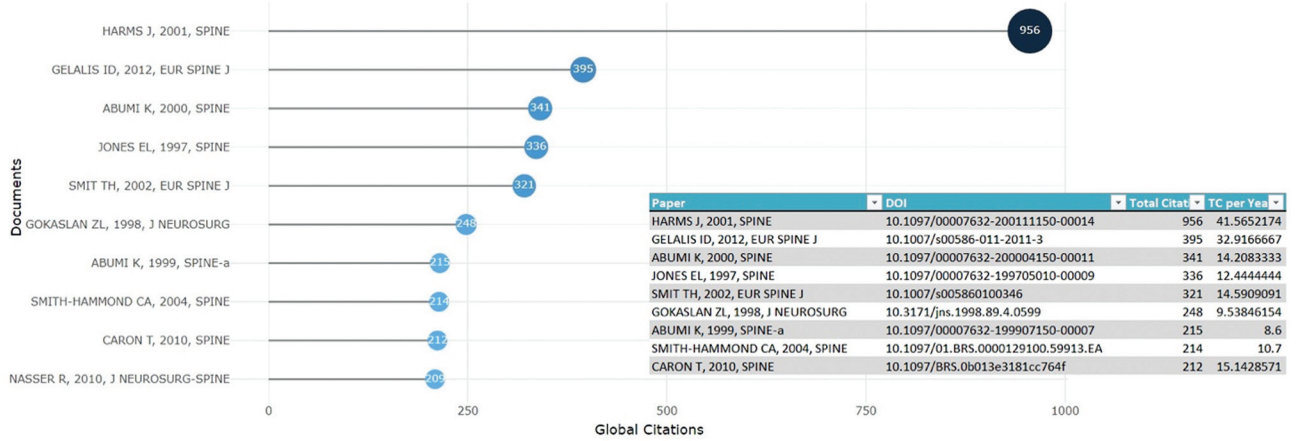


Node	Cluster	Betweenn
fixation	1	44.066224
spine	1	39.8015162
complications	1	20.8170269

Node	Cluster	Betweenn
anterior	2	3.67080042
decompression	2	2.43136968
plate fixation	2	1.64601029
follow-up	2	1.26700037

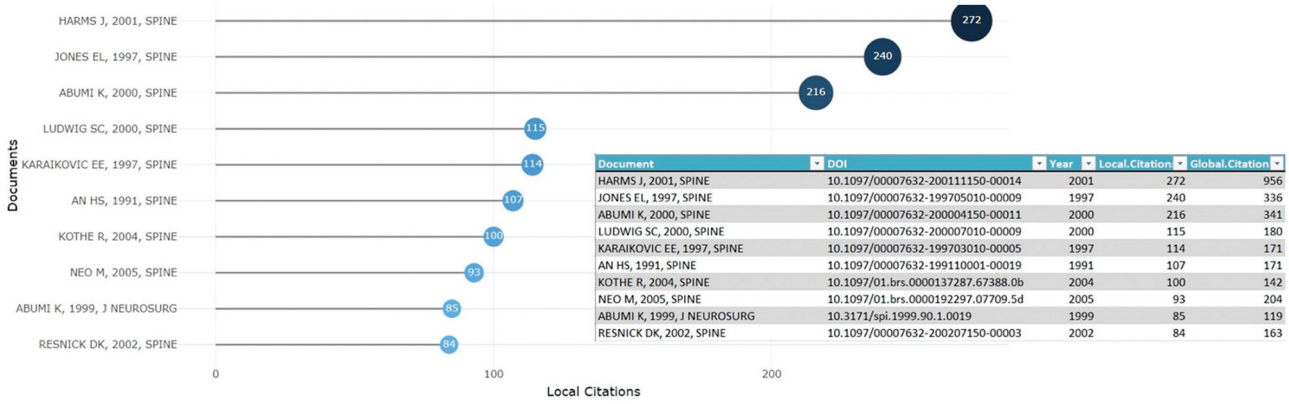
Node	Cluster	Betweenn
fusion	3	50.1906631
cervical-spine	3	16.9950958
stabilization	3	13.2559175
instrumentation	3	9.19901907

Fig. 20 Co-word network.



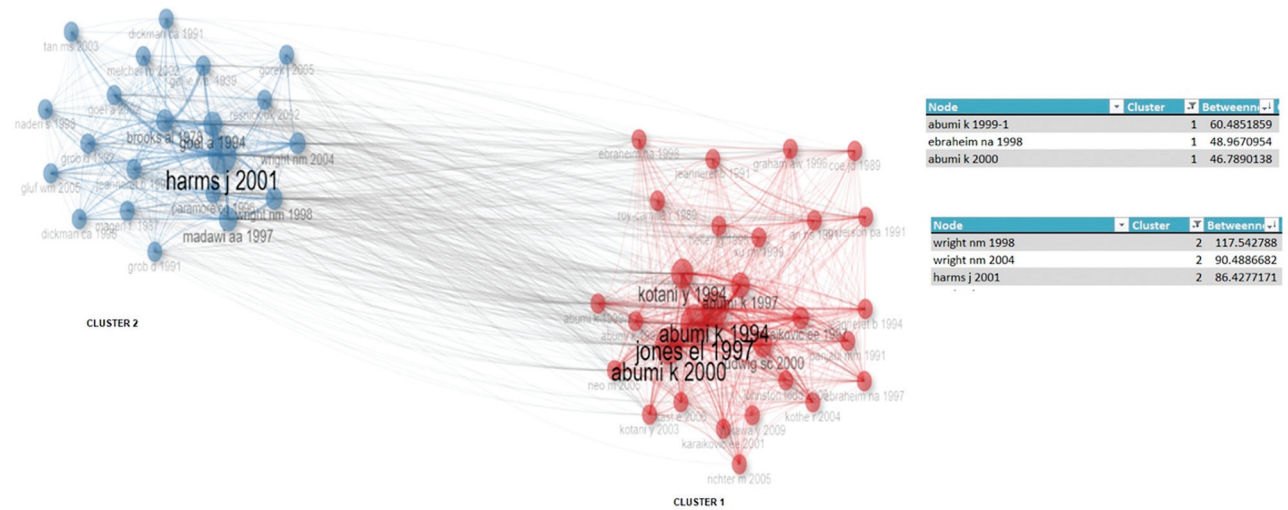
Paper	DOI	Total Citat	TC per Yea
HARMS J, 2001, SPINE	10.1097/00007632-200111150-00014	956	41.5652174
GELALIS ID, 2012, EUR SPINE J	10.1007/s00586-011-2011-3	395	32.9166667
ABUMI K, 2000, SPINE	10.1097/00007632-200004150-00011	341	14.2083333
JONES EL, 1997, SPINE	10.1097/00007632-199705010-00009	336	12.4444444
SMIT TH, 2002, EUR SPINE J	10.1007/s005860100346	321	14.5909091
GOKASLAN ZL, 1998, J NEUROSURG	10.3171/jns.1998.89.4.0599	248	9.53846154
ABUMI K, 1999, SPINE-a	10.1097/00007632-199907150-00007	215	8.6
SMITH-HAMMOND CA, 2004, SPINE	10.1097/01.BRS.0000129100.59913.EA	214	10.7
CARON T, 2010, SPINE	10.1097/BRS.0b013e3181cc764f	212	15.1428571

Fig. 21 Most global cited document.



Document	DOI	Year	Local.Citation	Global.Citation
HARMS J, 2001, SPINE	10.1097/00007632-200111150-00014	2001	272	956
JONES EL, 1997, SPINE	10.1097/00007632-199705010-00009	1997	240	336
ABUMI K, 2000, SPINE	10.1097/00007632-200004150-00011	2000	216	341
LUDWIG SC, 2000, SPINE	10.1097/00007632-200007010-00009	2000	115	180
KARAIKOVIC EE, 1997, SPINE	10.1097/00007632-199703010-00005	1997	114	171
AN HS, 1991, SPINE	10.1097/00007632-199110001-00019	1991	107	171
KOTHE R, 2004, SPINE	10.1097/01.brs.0000137287.67388.0b	2004	100	142
NEO M, 2005, SPINE	10.1097/01.brs.0000192297.07709.5d	2005	93	204
ABUMI K, 1999, J NEUROSURG	10.3171/spi.1999.90.1.0019	1999	85	119
RESNICK DK, 2002, SPINE	10.1097/00007632-200207150-00003	2002	84	163

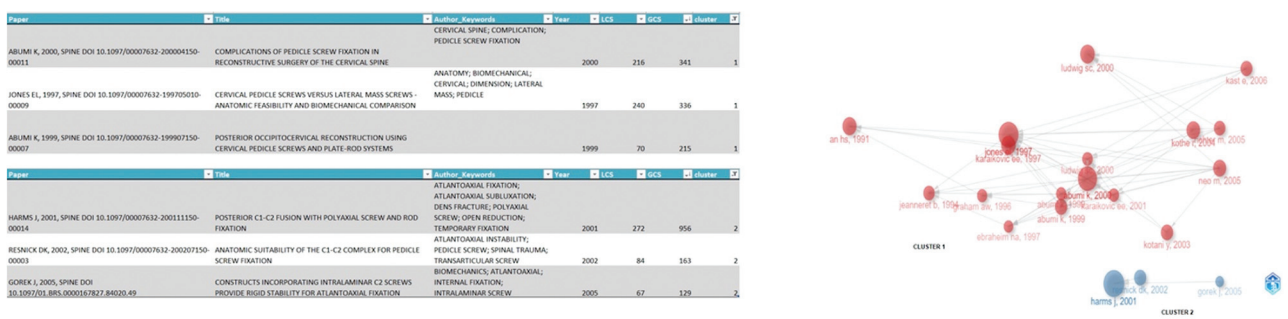
Fig. 22 Most local cited document.



Node	Cluster	Betweenn
abumi k 1999-1	1	60.4851859
ebraheim na 1998	1	48.9670954
abumi k 2000	1	46.7890138

Node	Cluster	Betweenn
wright nm 1998	2	117.542788
wright nm 2004	2	90.4886682
harms j 2001	2	86.4277171

Fig. 23 Co-citation network.



Paper	Title	Author_Keywords	Year	LCS	GCS	cluster
ABUMI K, 2000, SPINE DOI 10.1097/00007632-200004150-00011	COMPLICATIONS OF PEDICLE SCREW FIXATION IN RECONSTRUCTIVE SURGERY OF THE CERVICAL SPINE	CERVICAL SPINE; COMPLICATION; PEDICLE SCREW FIXATION	2000	216	341	1
JONES EL, 1997, SPINE DOI 10.1097/00007632-199705010-00009	CERVICAL PEDICLE SCREWS VERSUS LATERAL MASS SCREWS - ANATOMIC FEASIBILITY AND BIOMECHANICAL COMPARISON	ANATOMY; BIOMECHANICAL; CERVICAL; DIMENSION; LATERAL MASS; PEDICLE	1997	240	336	1
ABUMI K, 1999, SPINE DOI 10.1097/00007632-199907150-00007	POSTERIOR OCCIPITOCERVICAL RECONSTRUCTION USING CERVICAL PEDICLE SCREWS AND PLATE-ROD SYSTEMS		1999	70	215	1

Paper	Title	Author_Keywords	Year	LCS	GCS	cluster
HARMS J, 2001, SPINE DOI 10.1097/00007632-200111150-00014	POSTERIOR C1-C2 FUSION WITH POLYAXIAL SCREW AND ROD FIXATION	ATLANTOAXIAL FIXATION; ATLANTOAXIAL SUBLUXATION; DENS FRACTURE; POLYAXIAL SCREW; OPEN REDUCTION; TEMPORARY FIXATION	2001	272	956	2
RESNICK DK, 2002, SPINE DOI 10.1097/00007632-200207150-00003	ANATOMIC SUITABILITY OF THE C1-C2 COMPLEX FOR PEDICLE SCREW FIXATION	ATLANTOAXIAL INSTABILITY; PEDICLE SCREW; SPINAL TRAUMA; TRANSARTICULAR SCREW	2002	84	163	2
GOREK J, 2005, SPINE DOI 10.1097/01.BRS.0000167827.84020.49	CONSTRUCTS INCORPORATING INTRALAMINAR C2 SCREWS PROVIDE RIGID STABILITY FOR ATLANTOAXIAL FIXATION	BIOMECHANICS; ATLANTOAXIAL; INTERNAL FIXATION; INTRALAMINAR SCREW	2005	67	129	2

Fig. 24 Historiograph.

particularly devoted to the subject and several other groups containing the same number of articles as the nucleus. The number of articles in the nucleus and the succeeding groups will be 1:n:n^2:..." The law is useful to assess the completeness of data, which gives a smooth curve on the graph. The graph also helps us to know the specific journals that are most relevant to the topic.[27] A team of authors are usually involved in the publication process; only 40 out of a total of 1953 publications were by a single author. The collaboration was mostly among authors from within the country as the international co-authorship was seen in only 13.11% of the publications. United States being the leading country in terms of number of publications has the maximum number of authors involved in publications. The international collaboration is found only in 13.7% of the publications from United States' similarly the "MCP ratio" for high-volume countries like China (0.08), Japan (0.03), and Korea (0.17) is also very low, while the MCP ratio for countries with

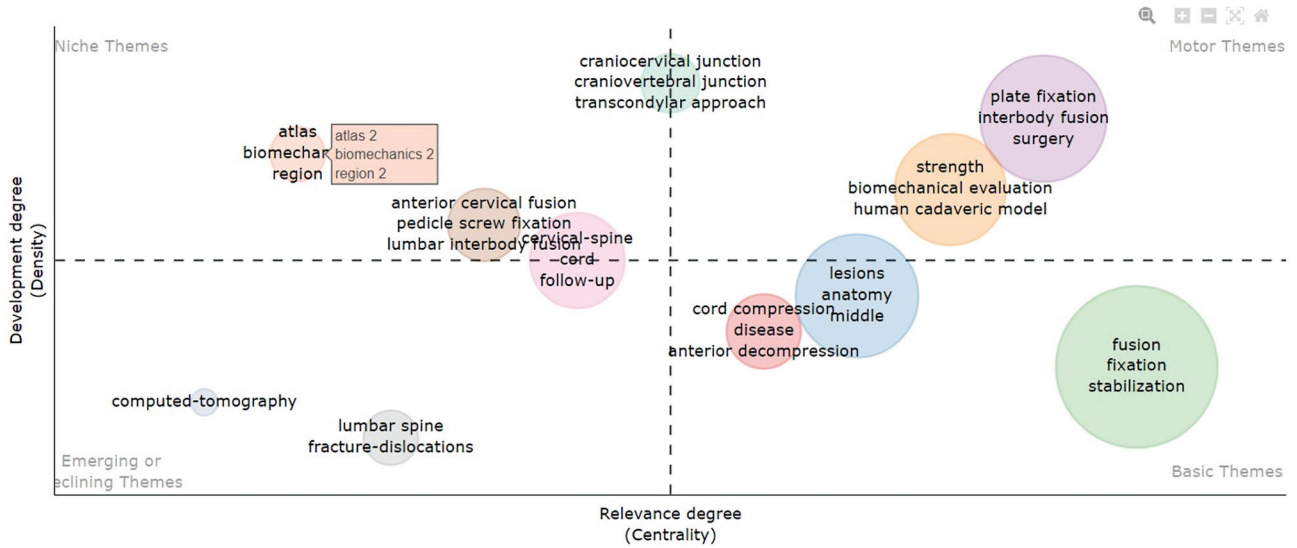
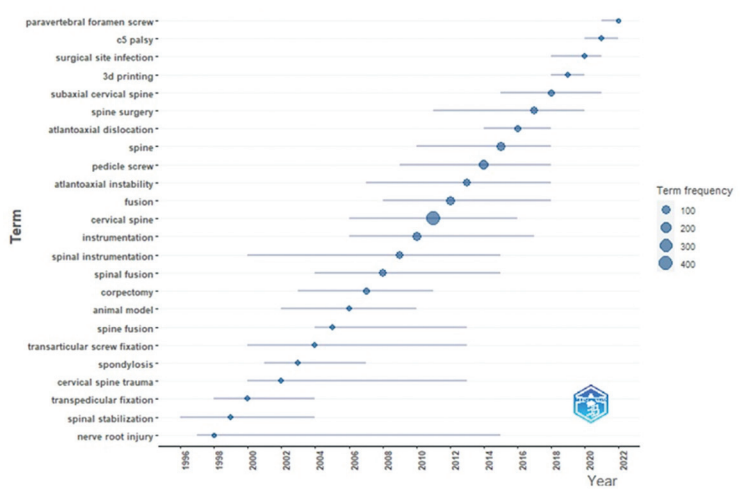


Fig. 25 Thematic map.



item	freq	year_q1	year_med	year_q3
nerve root injury	5	1997	1998	2015
spinal stabilization	6	1996	1999	2004
transpedicular fixation	13	1998	2000	2004
cervical spine trauma	8	2000	2002	2013
spondylosis	9	2001	2003	2007
transarticular screw fixation	14	2000	2004	2013
spine fusion	14	2004	2005	2013
animal model	6	2002	2006	2010
corpectomy	29	2003	2007	2011
spinal fusion	52	2004	2008	2015
spinal instrumentation	57	2000	2009	2015
instrumentation	98	2006	2010	2017
cervical spine	440	2006	2011	2016
fusion	84	2008	2012	2018
atlantoaxial instability	63	2007	2013	2018
pedicle screw	152	2009	2014	2018
spine	88	2010	2015	2018
atlantoaxial dislocation	29	2014	2016	2018
spine surgery	40	2011	2017	2020
subaxial cervical spine	32	2015	2018	2021
3d printing	7	2018	2019	2020
surgical site infection	10	2018	2020	2021
c5 palsy	11	2020	2021	2022
paravertebral foramen screw	5	2021	2022	2022

Fig. 26 Trend topics.

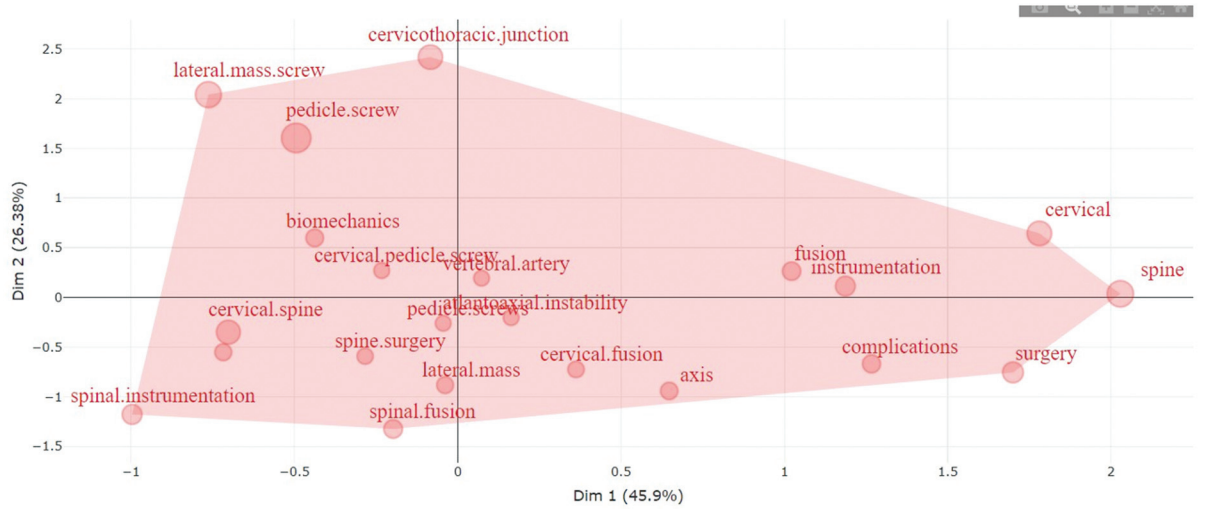


Fig. 27 Factorial analysis.

WOS DATA SHEET

Metadata	Description	Missing Counts	Missing %	Status
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
NR	Number of Cited References	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
WC	Science Categories	2	0.10	Good
PY	Publication Year	18	0.90	Good
CR	Cited References	21	1.05	Good
AB	Abstract	23	1.15	Good
C1	Affiliation	25	1.25	Good
RP	Corresponding Author	54	2.70	Good
ID	Keywords Plus	71	3.55	Good
DI	DOI	89	4.45	Good
DE	Keywords	154	7.69	Good

PUBMED DATA SHEET

Metadata	Description	Missing Counts	Missing %	Status
DT	Document Type	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
AU	Author	1	0.03	Good
SO	Journal	1	0.03	Good
AB	Abstract	51	1.70	Good
C1	Affiliation	80	2.67	Good
DE	Keywords	419	14.00	Acceptable
ID	Keywords Plus	419	14.00	Acceptable
DI	DOI	996	33.29	Poor
CR	Cited References	2992	100.00	Completely missing
RP	Corresponding Author	2992	100.00	Completely missing
NR	Number of Cited References	2992	100.00	Completely missing
WC	Science Categories	2992	100.00	Completely missing

SCOPUS DATA SHEET

Metadata	Description	Missing Counts	Missing %	Status
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
DI	DOI	320	10.93	Acceptable
AB	Abstract	2927	100.00	Completely missing
C1	Affiliation	2927	100.00	Completely missing
CR	Cited References	2927	100.00	Completely missing
RP	Corresponding Author	2927	100.00	Completely missing
DE	Keywords	2927	100.00	Completely missing
ID	Keywords Plus	2927	100.00	Completely missing
LA	Language	2927	100.00	Completely missing
NR	Number of Cited References	2927	100.00	Completely missing
WC	Science Categories	2927	100.00	Completely missing

Fig. 28 Missing data table.

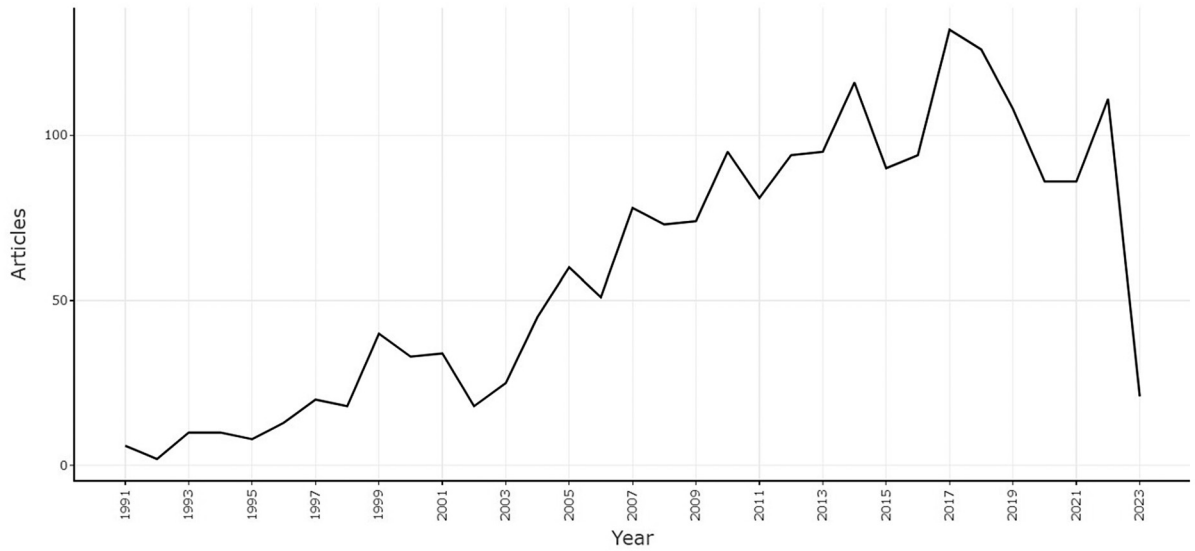


Fig. 29 Annual scientific production.

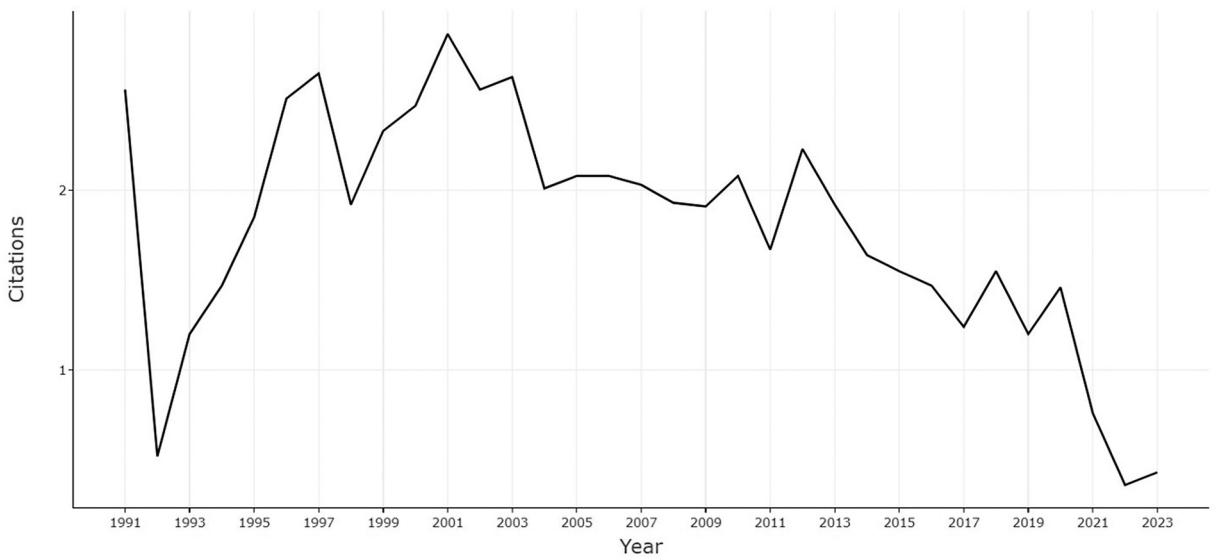


Fig. 30 Average citation per year.

comparatively low volume of articles published is much higher. This can be explained by the presence of necessary expertise and equipment needed for research and innovation within the country for United States, China, and Japan but the researchers from other countries have to depend on the assistance and collaboration from researchers of the above countries because their domestic set up is lacking. The researchers from United States, Japan, China, and Germany were pioneers in the related field and contributed to the development of cervical spine instrumentation. This explains the huge number of citations for the publications done by researchers from these countries. Co-word analysis gives a graphical representation of the keywords (descriptors) most commonly and strongly associated with the documents being analyzed. It is helpful in analyzing the content of the documents as well as identifying the popular topics and trends in the particular field of research. The words appearing clustered together show the strength of their association.[28]

Strengths and Limitations

It is the first comprehensive bibliometric analysis of over 30 years of research on posterior instrumentation of cervical spine. It has identified the most important journals, most relevant authors, most cited articles, nature and amount of collaboration among countries and authors, the landmark papers in the field, and the evolution of trending topics on the subject. The study gains its strength from the fact that data was collected from WOS that is a very comprehensive source and gives complete information regarding citations, indexing, and affiliations of the contributing authors. The bibliometric analysis was performed. Bibliometrix package of R software giving an automated and easy to understand result with beautiful illustration of all the tables generated. The main limitation is the time boundaries used for collection of studies that may have led to exclusion of some important articles and authors beyond the mentioned time period. We have also limited our study to the WOS as the only source of articles and not considered other sources like PubMed, Scopus, Google Scholar, etc.; thus, it may have missed on some important articles.

Conclusion

The findings of this study are important as they enhance the knowledge on the topic of posterior instrumentation of cervical spine and helps in decision making. They also help to highlight the gaps in present literature and could guide the trends and directions of future research and innovation in the field.

It is evident that research and publication have grown over the years. United States has emerged as a leader in terms of number of publications and citations. It is a leader in terms of author's collaboration too. The university of California, San Francisco, is the leading institute, while VKH Sonntag and RM Xu are the leading authors. The "Spine" journal is most relevant. The article by J Harms (DOI – 10.1097/00007632-200111150-00014, Spine, 2001) has been the most cited document. The most commonly used author's keyword is "fixation."

Funding
None.

Conflict of Interest
None declared.

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