Hot spots and trends in knee revision research since the 21st century: a bibliometric analysis

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Background: With the popularization of knee replacement surgery in the treatment of the advanced lesions of knee joint, the amount of knee revision surgery is increasing unceasingly. Meanwhile, the continuous introduction of new clinical concepts and new technology poses a challenge to researchers and surgeons. Our study aims to inform the future scientific research and clinical treatment, by investigating the hot spots and trends of the knee revision research field with the method of bibliometric analysis.

Methods: Publications on knee revision included in the database of Web of Science Core Collection (WoSCC) between 2000 and 2018 were reviewed and MeSH terms of them were extracted from PubMed. Online bibliometric analysis website (http://bibliometric.com/), two pieces of software called "CiteSpace" and "Bibliographic Item Co-Occurrence Matrix Builder" (BICOMB) were used to analyze the publications reviewed at quantitative level. Another piece of software called "gCLUTO", was used to investigate the hot spots with visualization techniques at qualitative level.

Results: A total of 906 publications were retrieved between 2000 and 2018. There is an increasing number of publications, from 15 in 2000 to 86 in 2018. *Journal of Arthroplasty* is the leading journal which has the most publications on knee revision. The United States has been the biggest contributor. Mayo Clinic became the leader among the institutions which have conducted correlational researches. David G. Lewallen, Robert L. Barrack and Michael A. Mont should be regarded as the scholars who have made outstanding contribution. Hot spots were summed up in six clusters, respectively, the solutions for infection, prostheses, the adverse effects, the surgical techniques, epidemiological characters, and the pathophysiology of the revision knee.

Conclusions: We found a growing trend in knee revision research and extracted the most contributive researchers, institutions, countries, journals, and most-cited articles worldwide. The solutions for complications, surgical applications and analysis for epidemiological characters have been the hot spots. Multi-disciplinary integration is becoming the time-trend of hot spots. Minimally invasive and navigation are directions of revision surgery. They together constitute a solid foundation and set up a fingerpost for the future scientific research and clinical treatment.

Keywords: Knee revision; hot spots; trends; bi-clustering co-word analysis; visualization

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Introduction

Joint replacement—honored as an epoch-making operation (1), is a most effective treatment method for the advanced lesion of knee joint. It mainly aims to release the pain thoroughly, correct the alignment and improve the ROM (range of motion) of joint through replacing the broken cartilage and osteophyte on the joint surface with artificial materials. With the development of global population aging and people's demand of higher living quality, the amount of knee replacement surgery is increasing by years. One retrospective study noticed a nearly 27-fold increase in total knee arthroplasty (TKA) utilization rates in the past decade between 18 different countries (2). However, the artificial prosthesis is not a permanent choice. According to a retrospective survey conducted by Mayo Clinic in 2011, the fifteen-year survival of different prostheses is about 77% to 90% (3). A variety of postoperative complications at short-term or long-term may appear, which will result in loss of joint function and even amputation or death if not be disposed in time. Therefore, it is of great significance to conduct knee revision properly and timely.

Revision refers to an operation in which at least one component of the prosthesis need to be replaced, including femoral, patellar, tibial components and the polyethylene line (4). Recently, the number of revision cases has increased a lot, which owes greatly to the rapid increase of primary knee replacement (5). One prospective study predicted that the revision rate in 2030 will be 6 times higher than that of 2005 (6). Meanwhile, new technology and clinical concepts have been introduced continually. Based on that, the hot spots and trends in knee revision research field also have changed over years, which poses a challenge to researchers and surgeons. Groups of scholars and professors have made great efforts and many papers have been published so far, though, lack of a summative review. Therefore, we think it is very essential to make a comprehensive review of this area, from which the new comers as well as the old stagers in this research area can benefit a lot.

Bibliometrics is an interdisciplinary science that uses mathematical and statistical methods to quantitatively analyze all knowledge carriers, especially for scientific publications (7). It plays an important role in revealing the law of the publications and predicting the future direction of the discipline. The co-word analysis method was first described in detail in the middle and late 1970s by French bibliographers. Since then, co-word analysis has been widely used in many fields. Researchers use the basic principles of the co-word method to summarize the hotspots of the research field, to analyze the development process, characteristics of the disciplines horizontally and vertically, to reveal the relationship between the fields or disciplines, to reflect the dynamic and static structures of the research level of a certain subject and its development history, and so on. Till now, it has developed into a discipline with variable statistical analysis methods for different research requirements, including cluster analysis, factor analysis, multi-variate analysis, multi-dimensional scaling analysis and so on. In recent years, bi-clustering analysis has been more popular in the field of bibliometrics. For example, the research trend of the use of stent implantation in the pancreatic diseases has been predicted by Zhu *et al*. with the method of bi-clustering analysis (8). Another latest bibliometric study on scoliosis research also applied bi-clustering analysis (9).

Knee revision has always been one of the top-intractable issues for researchers and surgeons, but there was no bibliometric study on it. Our research aims to provide an integrated appraisement of the scientific payoffs of knee revision since the 21st century through co-word bi-clustering analysis. By identifying the hot spots and trends, we hope that our findings might constitute a solid foundation and set up a fingerpost to inform the future research and clinical treatment on knee revision.

Methods

Data collection and materials preparation

On March 16th,2020, publications on knee revision included in the database of Web of Science Core Collection (WoSCC) between January 1st, 2000 and December 31st, 2018 were retrieved. The search command was "Knee revision" OR "Revision total knee revision" OR "Revision TKA", which was under the "basic search" feature and the "title" category. Only articles and reviews were reserved. Then we exported the full record and cited references of them to text-format files, which were prepared to be imported into "CiteSpace (V5.6.R3)" and an online bibliometric analysis website (http://bibliometric.com/) for bibliometric analysis. All of the publications were saved as XML-format files from PubMed, which can be utilized for co-word bi-clustering analysis according to the MeSH words (10). They were prepared to join in another piece of software "Bibliographic Item Co-Occurrence Matrix Builder" (BICOMB) to sum up hot spots (11).

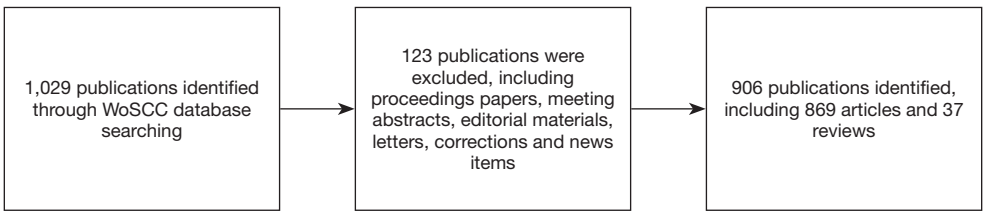


Figure 1 Flow chart of literature screening.

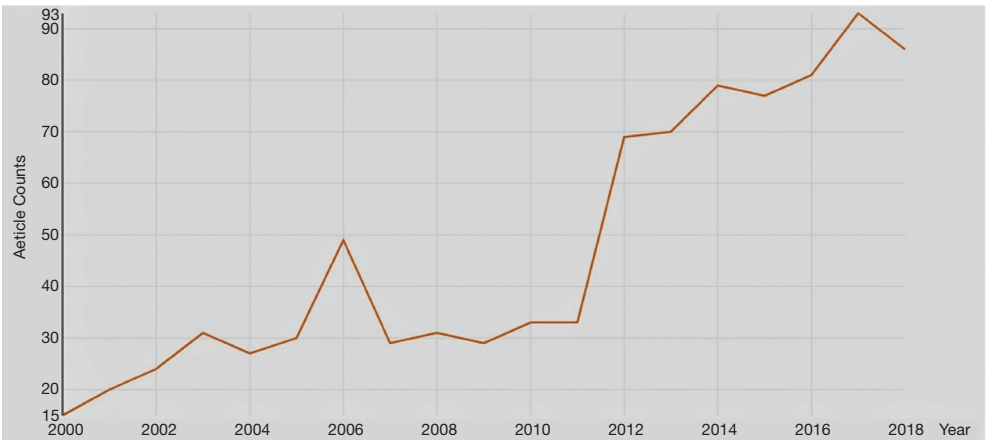


Figure 2 The number of articles on knee revision published from 2000 to 2018.

Statistical analysis

The online bibliometric analysis website (http://bibliometric.com/) was used to calculate the quantity of the publications in different views, such as years, countries and authors, the tendencies of which would come out as visualization results. Citespace was used to analyze the collaboration network of the journals, authors, countries and institutions as well as the top cited articles with a visualized presentation (12). To further analyze the scientificity of the study, the latest impact factor (IF) and the citation number of the retrieved articles were checked.

To investigate the hot spots of knee revision, we introduced the methods of co-word bi-clustering analysis, which is applied to identify the relationship between the articles and the high frequency words. BICOMB was utilized to figure out the proportion of the frequency permutations of the MeSH words in the retrieved publications. Meanwhile, we could get a co-word matrix of high-frequency MeSH words based on the G-index algorithm, which was prepared to be imported into "gCLUTO", v1.0 (13). gCLUTO is a piece of software specifically for visually analyzing the co-word matrix, from which research hotspots could be found by clustering the MeSH words and represented as a mountain visualization. In order to obtain an optimal map, we kept moderating the number of the clusters. Finally, the approximate number came out as six and we successfully established the fundamental framework with comprehensive contents of our study on knee revision.

Results

Distribution of publications

Overall distribution

A total of 906 publications on knee revision research, comprising 869 articles and 37 reviews recorded by the database of WoSCC, were retrieved finally (*Figure 1*). Generally speaking, it took on an increasing trend in the annual number of the publications from 2000 to 2018, which rose from 15 in 2000 to 86 in 2018. There particularly appeared an explosive growth in 2012 (*Figure 2*).

Distribution by countries and institutions

Based on online bibliometric analysis, these publications

Table 1 The top 10 countries or regions and institutions that published the most articles on knee revision

Rank	Country/region	Article counts	Institutions	Article counts	Institutions	Cited counts
1	USA	387	Mayo Clin	64	Mayo Clin	543
3	UK	100	Hosp Special Surg	32	Exponent Inc	528
2	Germany	85	Rush Univ	25	Univ Calif San Francisco	227
4	Canada	54	Univ Calif San Francisco	24	Univ Minnesota	211
5	France	34	Univ Western Ontario	20	Massachusetts Gen Hosp	168
6	Italy	32	Exponent Inc	20	Tulane Univ	160
7	Netherlands	30	Univ Penn	17	Univ Western Ontario	134
8	China	29	Thomas Jefferson Univ	16	Univ British Columbia	123
9	Denmark	26	Univ Minnesota	16	Mt Sinai Hosp	118
10	Spain	26	Haukeland Hosp	15	Mayo Clin & Mayo Fdn	106

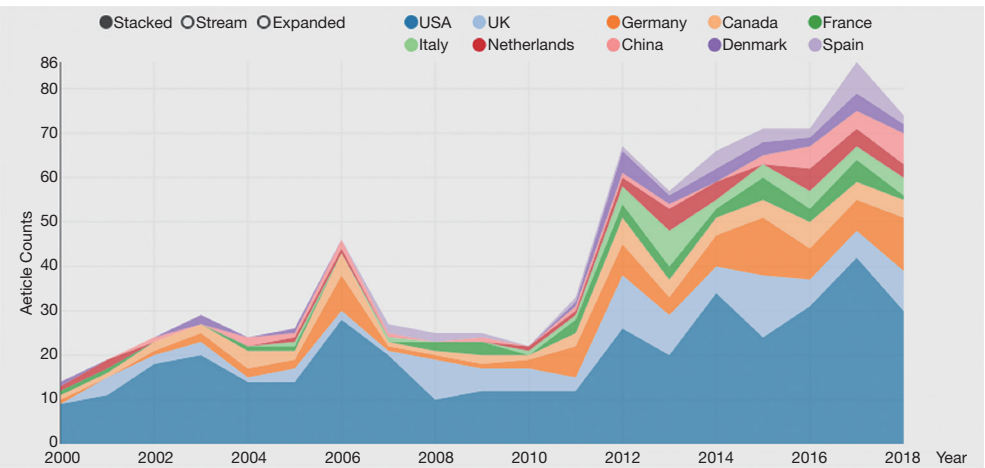


Figure 3 The trend of the top 10 countries/regions that published the most articles from 2000 to 2018.

on knee revision are stemmed from 32 different countries and 1,030 different institutions. The top 10 countries/regions and institutions are listed in *Table 1* and the trend of the top 10 countries/regions is shown in *Figure 3*. Till now, the United States (n=387) ranked the No. 1 country which had the most publications on knee revision, followed by the UK (n=100), Germany (n=85) and Canada (n=54). Mayo Clinic (n=64) and Hosp Special Surg (n=32) head the list of institutions, which indicates that they had make a great effort in this field. To figure out the authority of these institutions, we arranged the cited counts, then Mayo Clinic (n=548) and Exponent Inc (n=528) became the relatively best qualified to speak in the knee revision research field.

The density (=0.0046) of the network map of institutions is very low (*Figure 4*), which indicates that the cooperation between the institutions should be reinforced. The cooperation between global countries/regions is mapped in *Figure 5*. The United States and Canada became the closest partners.

There were 111 journals counted associated with the retrieved publications. The top 10 of them were listed in *Table 2*, accompanied with the latest IF score and H-index. Among the top 10 journals which had the most publications on knee revision, *Journal of Arthroplasty* (n=219) and *Clinical Orthopaedics and Related Research* (n=108) played a leading role with a percentage of 36% approximately of the 906 publications. And *Journal of Bone* and *Joint Surgery-American Volume* owned the highest IF score (4.716), followed by

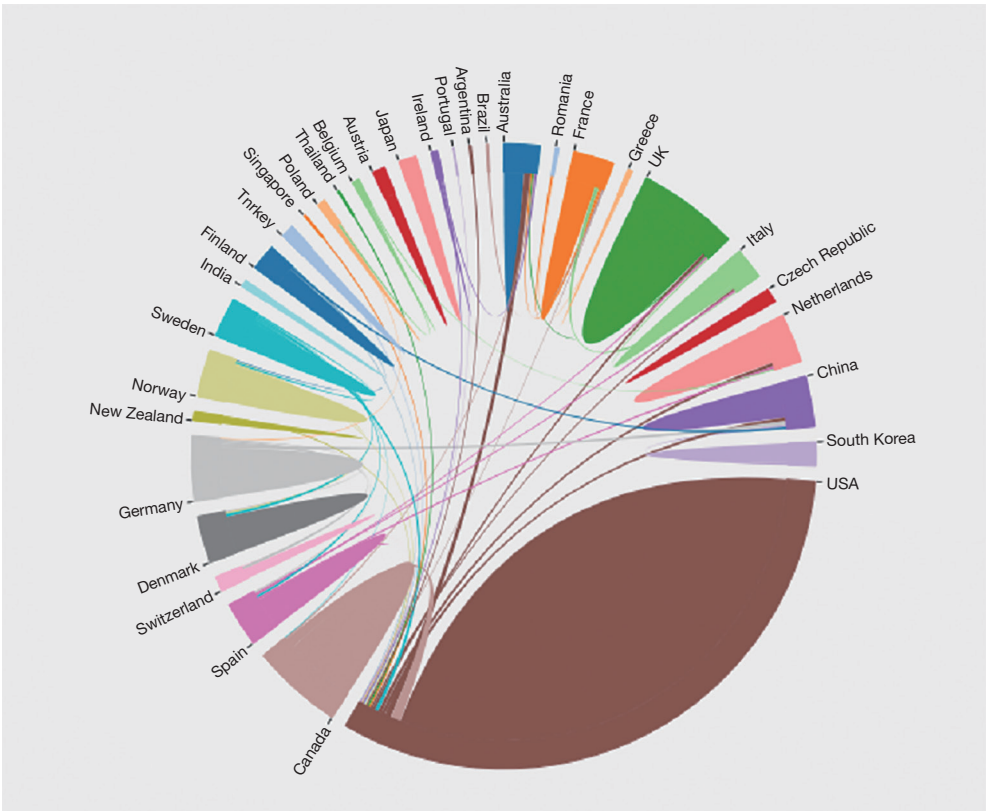


Figure 4 The network map of institutions that involved in knee revision research.

Bone & Joint Journal (4.301), *Clinical Orthopaedics and Related Research* (4.154), *Journal of Arthroplasty* (3.524), ACTA Arthopaedica (3.217) and *Knee Surgery Sports Traumatology Arthroscopy* (3.149).

Distribution by authors

There were 2,918 authors counted in this bibliometric study, of which the top 10 productive authors, first authors, corresponding authors and co-cited authors were ranked by the number of articles or citation counts in *Table 3*.

David G. Lewallen, from Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota, USA, lead the list of the top 10 productive authors with 21 articles published.

Robert L. Barrack, from Department of Orthopaedic Surgery, Washington University School of Medicine, St. Louis, Missouri, USA, became the most-times first author with 9 times.

Michael A. Mont, from Department of Orthopaedic Surgery, Lenox Hill Hospital, New York, USA, was the most-times corresponding author with 15 corresponding articles.

Edmund Lau, from Exponent, Inc., Menlo Park, California, USA, was the most-times cited authors with 312 citation counts.

Distribution by high-cited references

With the help of Citespace, we were able to analyze the cited information of the retrieved publications. A network map of the correlation of all references of the publications was set up in *Figure 6*. Depending on the number of cited-times counted, we made a list of the top 50 high-cited references in *Table 4*. These references could be considered as strong nodes or pillars of the research field of knee revision. They were the most classic publications with great reference value, from which either the new comers or the old stagers could acquire the research's background, the sum-up of study, the train of thoughts, as well as the new research's methods. Itis also very significant to predict the trend and hot spots of the research field by making a review of the high-cited references.

Research hotspots of knee revision research

With the utilization of BICOMB, 718 MeSH terms were

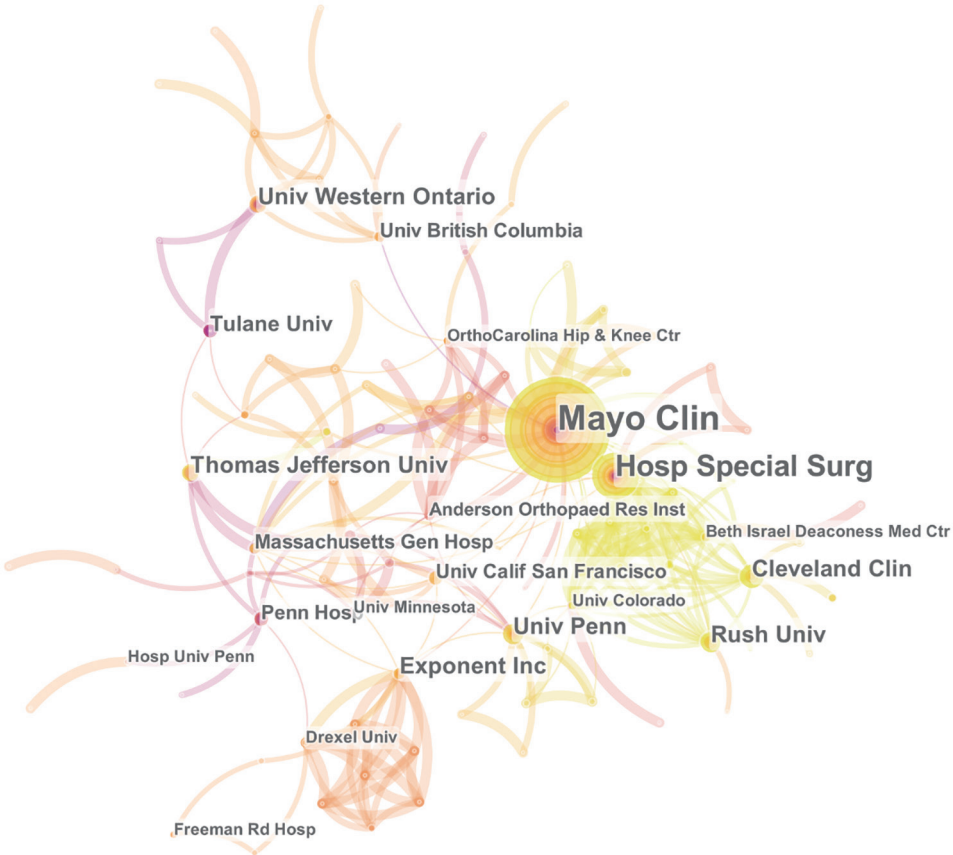


Figure 5 The international cooperation of countries or regions involved in knee revision research.

Table 2 The top 10 most active journals that published articles in knee revision research

Rank	Journal title	Article counts	Percentage (N=906)	IF (in 2019)	H-index	Total number of citations	Average number of citations
1	*Journal of Arthroplasty*	219	24.17%	3.524	119	1,172	5.35
2	*Clinical Orthopaedics and Related Research*	108	11.92%	4.154	185	1,030	9.54
3	*Knee*	57	6.29%	1.762	69	262	4.60
4	*Journal of Bone and Joint Surgery-American Volume*	56	6.18%	4.716	159	742	13.25
9	*Bone & Joint Journal*	51	5.63%	4.301	164	336	6.59
5	*Knee Surgery Sports Traumatology Arthroscopy*	46	5.08%	3.149	109	132	2.87
6	*International Orthopaedics*	34	1.10%	2.384	77	170	5.00
7	*Acta Orthopaedica*	31	3.42%	3.217	100	95	3.06
8	*Orthopedics*	29	3.20%	1.608	60	80	2.76
10	*Journal of Knee Surgery*	23	2.54%	1.591	52	10	0.43

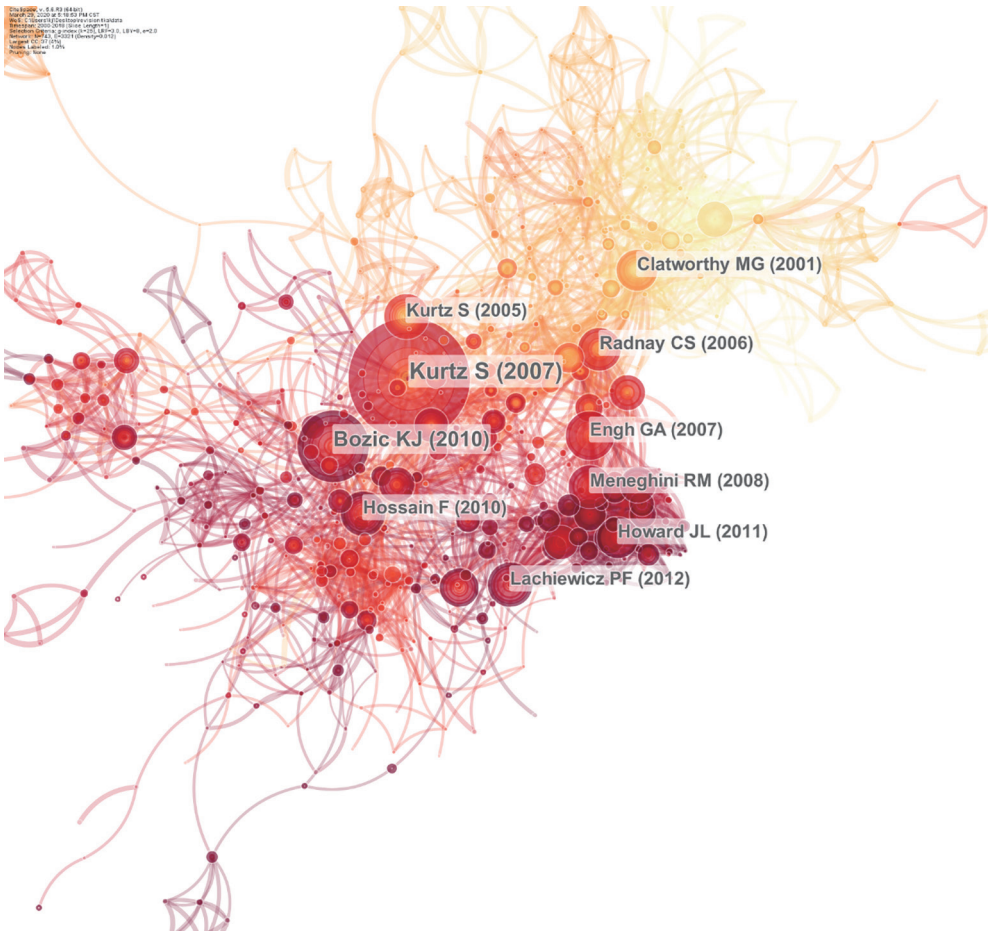


Figure 6 The network map of the correlation of all references of the publications on knee revision.

Table 3 The top 10 productive authors, first authors, corresponding authors and co-cited authors contributed to publications in knee revision research

Rank	Author	Article counts	First author	Article counts	Corresponding author	Article counts	Co-cited author	Citation counts
1	Lewallen	21	Barrack	9	Mont	15	Lau	312
2	Parvizi	20	Completo	7	Parvizi	11	Ong	272
3	Mont	19	Singh	6	Barrack	9	Hassen	258
4	Hanssen	15	Saleh	5	Saleh	7	Kurtz	233
5	Barrack	13	Nelson	5	Completo	7	Mowat	214
6	Della Valle	13	Whiteside	5	Singh	7	Lewallen	210
7	Masri	12	Fehring	4	Fehring	6	Halpern	193
8	Trousdale	11	Sheng	4	Trousdale	6	Berry	178
9	Saleh	11	Dennis	4	Dennis	5	Mason	159
10	Furnes	11	Lonner	4	Whiteside	5	Barrack	158

Table 4 The top 50 high-cited references of the publications on knee revision

Rank	Cited times	Year	First author	Title
1	81	2007	Kurtz	Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030
2	51	2010	Bozic	The epidemiology of revision total knee arthroplasty in the United States
3	33	2010	Hossain	Midterm assessment of causes and results of revision total knee arthroplasty
4	33	2007	Engh	Use of structural allograft in revision total knee arthroplasty in knees with severe tibial bone loss
5	32	2008	Meneghini	Use of porous tantalum metaphyseal cones for severe tibial bone loss during revision total knee replacement
6	31	2012	Lachiewicz	Can tantalum cones provide fixation in complex revision knee arthroplasty?
7	31	2005	Kurtz	Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 through 2002
8	30	2006	Radnay	Management of bone loss: augments, cones, offset stems
9	29	2011	Howard	Early results of the use of tantalum femoral cones for revision total knee arthroplasty
10	29	2001	Clatworthy	The use of structural allograft for uncontained defects in revision total knee arthroplasty A minimum five-year review
11	27	2011	Mortazavi	Failure following revision total knee arthroplasty: infection is the major cause
12	26	2006	Backstein	Management of bone loss: structural grafts in revision total knee arthroplasty
13	25	2009	Wood	Results of press-fit stems in revision knee arthroplasties
14	25	2009	Long	Porous tantalum cones for large metaphyseal tibial defects in revision total knee arthroplasty: a minimum 2-year follow-up
15	25	2009	Bauman	Limitations of structural allograft in revision total knee arthroplasty
16	24	2008	Suarez	Why do revision knee arthroplasties fail?
17	24	1995	Haas	Revision total knee arthroplasty with use of modular components with stems inserted without cement
18	22	2013	Alexander	Cementless metaphyseal sleeves used for large tibial defects in revision total knee arthroplasty
19	21	2003	Whaley	Cemented long-stem revision total knee arthroplasty
20	20	2015	Kamath	Porous tantalum metaphyseal cones for severe tibial bone loss in revision knee arthroplasty: a five to nine-year follow-up
21	20	2006	Lotke	Impaction grafting for bone defects in revision total knee arthroplasty
22	19	2010	Pearse	Survival and functional outcome after revision of a unicompartmental to a total knee replacement: the New Zealand National Joint Registry
23	19	2003	Fehring	Stem fixation in revision total knee arthroplasty: a comparative analysis
24	18	2013	Schmitz	Three-year follow up utilizing tantal cones in revision total knee arthroplasty
25	18	2011	Beckmann	Fixation of revision TKA: a review of the literature
26	18	2007	Saldanha	Revision of Oxford medial unicompartmental knee arthroplasty to total knee arthroplasty - results of a multicentre study
27	17	2013	Villanueva-Martinez	Tantalum cones in revision total knee arthroplasty A promising short-term result with 29 cones in 21 patients

Table 4 *(continued)*

Table 4 *(continued)*

Rank	Cited times	Year	First author	Title
28	17	2013	Rao	Tantalum cones for major osteolysis in revision knee replacement
29	17	2013	Agarwal	Metal metaphyseal sleeves in revision total knee replacement
30	17	2009	Kim	Revision total knee arthroplasty with use of a constrained condylar knee prosthesis
31	17	2009	Jamsen	Risk factors for infection after knee arthroplasty A register-based analysis of 43,149 cases
32	16	2014	Barnett	Use of stepped porous titanium metaphyseal sleeves for tibial defects in revision total knee arthroplasty: short term results
33	16	2009	Kurtz	Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030
34	16	2007	Mabry	The role of stems and augments for bone loss in revision knee arthroplasty
35	15	2015	Graichen	Direct, Cementless, Metaphyseal Fixation in Knee Revision Arthroplasty With Sleeves-Short-Term Results
36	15	2014	Derome	Treatment of large bone defects with trabecular metal cones in revision total knee arthroplasty: short term clinical and radiographic outcomes
37	15	2010	Mortazavi	Revision total knee arthroplasty infection: incidence and predictors
38	15	2007	Pour	Rotating hinged total knee replacement: use with caution
39	15	2006	Sheng	Revision total knee arthroplasty: 1990 through 2002 A review of the Finnish arthroplasty registry
40	15	2005	Hockman	Augments and allografts in revision total knee arthroplasty: usage and outcome using one modular revision prosthesis
41	15	2002	Sharkey	Insall Award paper Why are total knee arthroplasties failing today?
42	15	1999	Engh	Bone loss with revision total knee arthroplasty: defect classification and alternatives for reconstruction
43	15	1997	Peters	Revision total knee arthroplasty with a cemented posterior-stabilized or constrained condylar prosthesis: a minimum 3-year and average 5-year follow-up study
44	14	2011	Haidukewych	Metaphyseal fixation in revision total knee arthroplasty: indications and techniques
45	14	2010	Park	Comparison of static and mobile antibiotic-impregnated cement spacers for the treatment of infected total knee arthroplasty
46	14	2009	Meneghini	Use of porous tantalum metaphyseal cones for severe tibial bone loss during revision total knee replacement Surgical technique
47	14	2007	Mabry	Revision total knee arthroplasty with modular cemented stems: long-term follow-up
48	14	2007	Johnson	The survivorship and results of total knee replacements converted from unicompartmental knee replacements
49	14	1997	Engh	Treatment of major defects of bone with bulk allografts and stemmed components during total knee arthroplasty
50	13	2013	Schroer	Why are total knees failing today? Etiology of total knee revision in 2010 and 2011

amounted to 3,575 times in total. To avoid too much subjectivity in picking keywords in a bibliometric analysis, we specifically used G-index standard evaluation. It ultimately came out an appearance of more than 11 times that could make a MeSH term relatively high-frequency. 50 high-frequency MeSH terms, occupied 66.29%

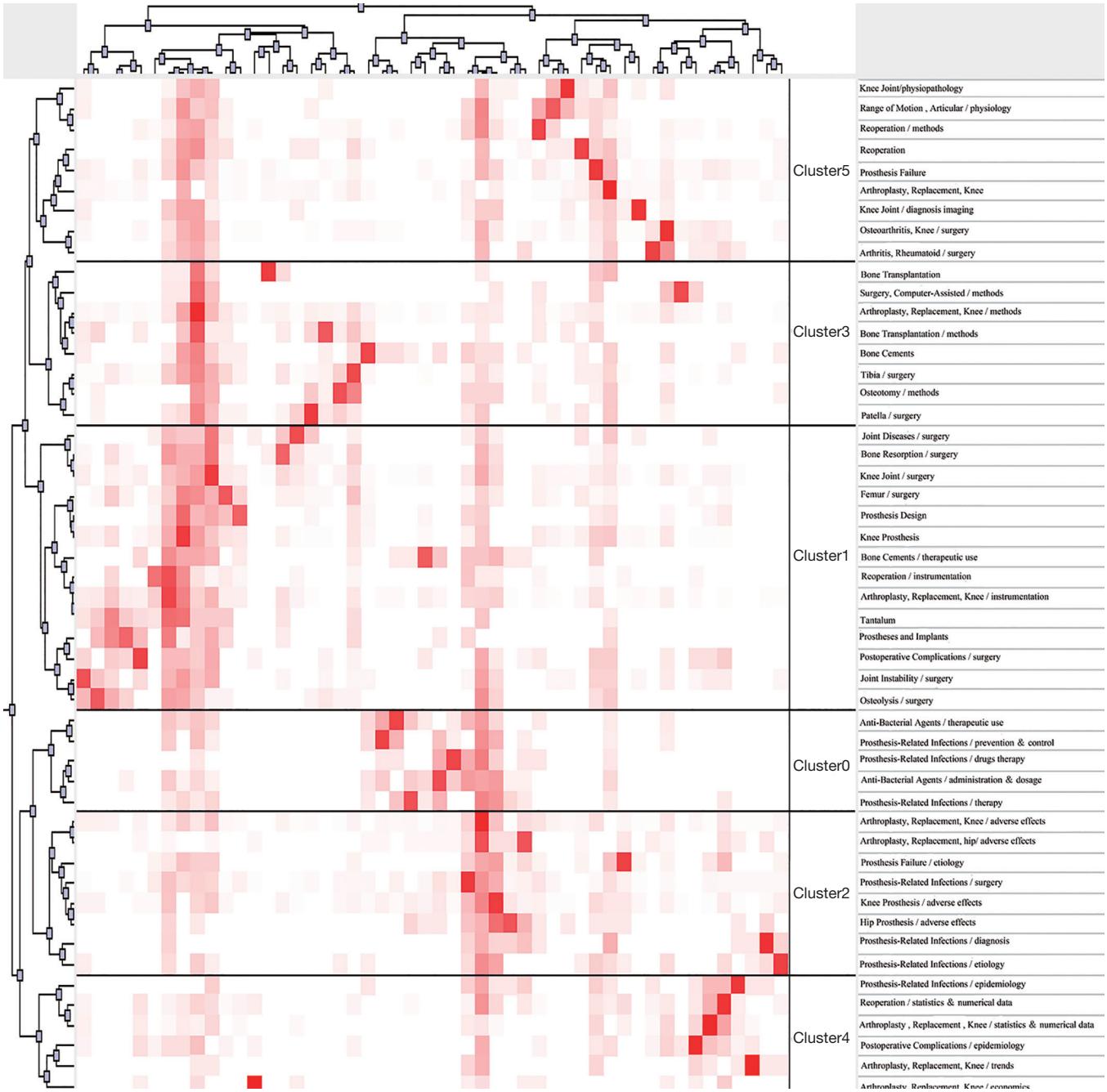


Figure 7 Visualized matrix of biclustering of highly frequent major MeSH terms and PMIDs of articles on knee revision. PMIDs, PubMed Unique Identifiers.

(2,370/3,575) of the overall frequency were displayed in *Table 5*.

With the use of BICOMB and gCLUTO, different amounts of clusters could be established for hot spots analysis. Then 4 to 10 clusters have been compared to choose an appropriate number of clusters as 6, which has a relatively higher intra-class similarity and a lower inter-class similarity. Matrix visualization was created in *Figure 7*. The clustering trees formed on the left of the *Figure 7* described the internal connection with the corresponding high-frequency MeSH

Table 5 Highly frequent major MeSH terms from the included publications on knee revision

Rank	Major MeSH terms/MeSH subheadings	Frequency	Proportion of frequency (%)	Cumulative percentage (%)
1	Arthroplasty, Replacement, Knee/methods	267	7.4685	7.4685
2	Arthroplasty, Replacement, Knee/adverse effects	264	7.3846	14.8531
3	Knee Prosthesis	215	6.0140	20.8671
4	Arthroplasty, Replacement, Knee	165	4.6154	25.4825
5	Knee Joint/surgery	156	4.3636	29.8462
6	Arthroplasty, Replacement, Knee/instrumentation	122	3.4126	33.2587
7	Knee Prosthesis/adverse effects	100	2.7972	36.0559
8	Prosthesis Failure	91	2.5455	38.6014
9	Prosthesis-Related Infections/surgery	82	2.2937	40.8951
10	Osteoarthritis, Knee/surgery	67	1.8741	42.7692
11	Tibia/surgery	57	1.5944	44.3636
12	Reoperation/statistics & numerical data	50	1.3986	45.7622
13	Arthroplasty, Replacement, Knee/statistics & numerical data	46	1.2867	47.0490
14	Reoperation/methods	42	1.1748	48.2238
15	Femur/surgery	34	0.9510	49.1748
16	Arthroplasty, Replacement, Hip/adverse effects	28	0.7832	49.9580
17	Postoperative Complications/epidemiology	27	0.7552	50.7133
18	Reoperation	27	0.7552	51.4685
19	Joint Instability/surgery	26	0.7273	52.1958
20	Bone Resorption/surgery	26	0.7273	52.9231
21	Postoperative Complications/surgery	25	0.6993	53.6224
22	Patella/surgery	23	0.6434	54.2657
23	Knee Joint/physiopathology	22	0.6154	54.8811
24	Tantalum	22	0.6154	55.4965
25	Prosthesis Failure/etiology	21	0.5874	56.0839
26	Prosthesis Design	21	0.5874	56.6713
27	Osteolysis/surgery	20	0.5594	57.2308
28	Arthroplasty, Replacement, Knee/economics	19	0.5315	57.7622
29	Reoperation/instrumentation	18	0.5035	58.2657
30	Anti-Bacterial Agents/administration & dosage	18	0.5035	58.7692
31	Osteotomy/methods	17	0.4755	59.2448
32	Joint Diseases/surgery	17	0.4755	59.7203
33	Range of Motion, Articular/physiology	16	0.4476	60.1678
34	Knee Joint/diagnostic imaging	16	0.4476	60.6154

Table 5 *(continued)*

Table 5 *(continued)*

Rank	Major MeSH terms/MeSH subheadings	Frequency	Proportion of frequency (%)	Cumulative percentage (%)
35	Bone Cements	16	0.4476	61.0629
36	Prosthesis-Related Infections/prevention & control	15	0.4196	61.4825
37	Prosthesis-Related Infections/etiology	15	0.4196	61.9021
38	Arthroplasty, Replacement, Knee/trends	15	0.4196	62.3217
39	Arthritis, Rheumatoid/surgery	14	0.3916	62.7133
40	Bone Transplantation	14	0.3916	63.1049
41	Anti-Bacterial Agents/therapeutic use	13	0.3636	63.4685
42	Prosthesis-Related Infections/diagnosis	13	0.3636	63.8322
43	Prosthesis-Related Infections/therapy	11	0.3077	64.1399
44	Surgery, Computer-Assisted/methods	11	0.3077	64.4476
45	Bone Cements/therapeutic use	11	0.3077	64.7552
46	Prostheses and Implants	11	0.3077	65.0629
47	Prosthesis-Related Infections/epidemiology	11	0.3077	65.3706
48	Hip Prosthesis/adverse effects	11	0.3077	65.6783
49	Prosthesis-Related Infections/drug therapy	11	0.3077	65.9860
50	Bone Transplantation/methods	11	0.3077	66.2937

terms on the right side. Transverse lines separated them into 6 clusters, which sequentially were cluster 5, 3, 1, 0, 2, 4 from top to bottom. The clustering trees formed on the top of the *Figure* 7 reflected the relationships among publications, which were one-one correspondence to MeSH term on the right side. Different colors stand for different values in the matrix. Deeper red represents more times of the appearance of MeSH terms in a publication, while white is opposite. Meanwhile, three-dimentional landform map was also created to visualize the matrix of MeSH terms of the retrieved publications (*Table 6*). Each cluster with its number was displayed as a mountain peak in the map (from 0 to 5, a total of 6 clusters) (*Figure 8*). The curve of each mountain peak was a Gaussian curve, which could approximately reflect the distribution of the data in the associated cluster by its position, volume, height, and color. Position represents the intra-cluster similarity. Height reflects the inter-cluster similarity, where exists a positive correlation. There also exists a positive correlation between the volume and the amount of high-frequency MeSH terms inside the cluster. And only the color at the top of the peak is meaningful, which reveals the inter-cluster standard deviation. Red means low deviation, while blue means high deviation.

Through the in-depth mining of publications, we identified the themes of all the clusters. They were, respectively:

(I) The solutions for infection associated to knee revision (Cluster 0);
(II) The prostheses for revision (Cluster 1);
(III) The adverse effects of revision (Cluster 2);
(IV) The surgical techniques for revision (Cluster 3);
(V) The epidemiological characters of revision (Cluster 4);
(VI) The pathophysiology of the revision knee (Cluster 5).

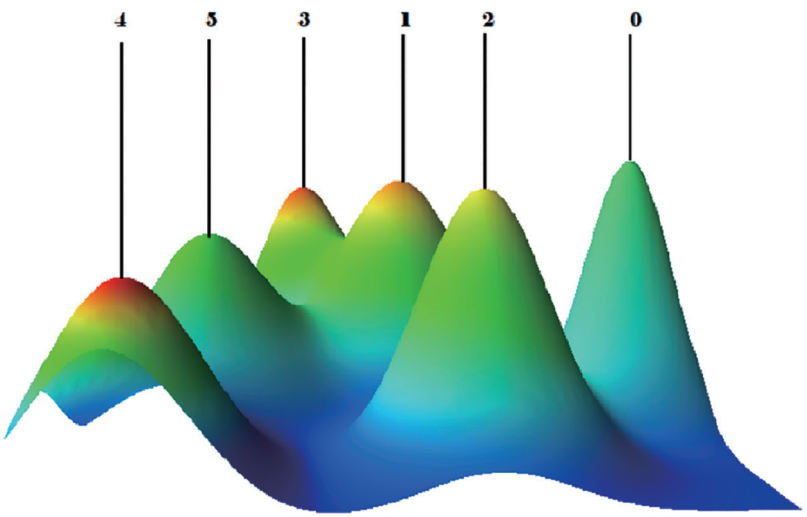
Discussion

We found a growth trend of the researches on knee revision since the 21st century with the application of the scientific statistical analysis. The analysis depended on the online bibliometric analysis website (http://bibliometric.com/), two pieces of software "CiteSpace" and "BICOMB". We made our search strategy broad to minimize omissions and to have a relatively comprehensive sets of articles so that the MeSH terms of them can map the hot spots and trends

Table 6 Highly frequent major MeSH terms/MeSH subheadings—PMIDs of source publications matrix

No.	Major MeSH terms/MeSH subheadings	PubMed Unique Identifiers of source publications				
		10693556	10743993	10744003	…	30809942
1	Arthroplasty, Replacement, Knee/methods	0	0	1	…	1
2	Arthroplasty, Replacement, Knee/adverse effects	0	0	0	…	0
3	Knee Prosthesis	0	0	0	…	0
4	Arthroplasty, Replacement, Knee	1	1	0	…	0
…	…	…	…	…	…	…
49	Prosthesis-Related Infections/drug therapy	0	0	0	…	0
50	Bone Transplantation/methods	0	0	0	…	0

PMIDs, PubMed Unique Identifiers.



Cluster	MeSH Terms
0	Anti-Bacterial Agents / therapeutic use
	Prosthesis-Related Infections / prevention & control
	Prosthesis-Related Infections / drug therapy
	Anti-Bacterial Agents / administration & dosage
	Prosthesis-Related Infections / therapy
1	Joint Diseases / surgery
	Bone Resorption / surgery
	Knee Joint / surgery
	Femur / surgery
	Prosthesis Design
	Knee Prosthesis
	Bone Cements / therapeutic use
	Reoperation / instrumentation
	Arthroplasty, Replacement, Knee / instrumentation
	Tantalum
	Prostheses and Implants
	Postoperative Complications / surgery
	Joint Instability / surgery
	Osteolysis / surgery
2	Arthroplasty, Replacement, Knee / adverse effects
	Arthroplasty, Replacement, Hip / adverse effects
	Prosthesis Failure / etiology
	Prosthesis-Related Infections / surgery
	Knee Prosthesis / adverse effects
	Hip Prosthesis / adverse effects
	Prothesis-Related Infections / diagnosis
	Prothesis-Related Infections / etilogy
3	Bone Transplantation
	Surgery, Computer-Assisted / methods
	Arthroplasty, Replacement, Knee / methods
	Bone Transplantation / methods
	Bone Cements
	Tibia / surgery
	Osteotomy / surgery
	Patella / surgery
4	Prosthesis-Related Infections / epidemiology
	Reoperation / statistics & numercial data
	Arthroplasty, Replacement, Knee / statistics & numercial data
	Postoperative Complications / epidemiology
	Arthroplasty, Replacement, Knee / trends
	Arthroplasty, Replacement, Knee / economics
5	Knee Joint / physiopathology
	Range of Motion, Articular / physiology
	Reoperation / methods
	Reoperation
	Prosthesis Failure
	Arthroplasty, Replacement, Knee
	Knee Joint / diagnostic imaging
	Osteoarthritis, Knee / surgery
	Arthritis, Rheumatoid / surgery

Figure 8 Mountain visualization of biclustering of highly frequent major MeSH terms and articles on knee revision.

more efficiently. Similar MeSH terms are identified and divided into different clusters by gCLUTO. Through the process above, a systemic analysis framework on the hot spots and trends of knee revision was set up.

Cluster 0 relates to the solutions for infection associated to knee revision. Infection is the major cause of revision (4), which must be solved. The exploration and controversy of treatment for infection have never stopped.

The selection of opportunity and treatment method should be placed into priority. In clinic, two-stage revision has long been regarded as the golden criterion before. However, with the development of clinic technique, there are increasing doubts on the drawbacks, such as twice operations at least, poor functional activities between the two stages and more costs. Based on that, new treatment methods were applied and the curative effects were observed, for example, debridement with prosthesis retention and anti-biotherapy (14). However, different treatment methods have their unique advantages. To some extent, the selection can be up to the type of infection (15).

Great efforts have been paid in the choice, course, and administration of the antibiotics. As early as 2001, Walenkamp GH reviewed the applications of absorbable gentamicin-loaded collagen and non-absorbable gentamicin-loaded bone cement in knee revision (16). In 2009, Chiu and Lin verified the effectiveness of vancomycin impregnated cement and in 2015 (17), low-dose vancomycin through intraosseous regional administration was applied to prevention, which achieves tissue concentrations at a higher level than systemic administration (18). Lately, Teicoplanin has become an efficient drug for antibiosis in spacers (19). Otherwise, five-day course of antibiotics appeared to control the recurrent infection better than one-day course (20).

Different spacers have been extensively tried and compared in two-stage infective revision, such as the gentamicin-loaded bone cement (21), the PROSTALAC spacer (22) and so on. The utilization of spacers can reduce pain, improve life quality between the two stages and it also make it easier to implant prostheses again (23). Compared with static spacers, articulating spacers can increase ROM, promote reimplantation, reduce reinfection rate and bone loss (24).

Cluster 1 relates to the prostheses for revision. The prosthesis is the most pivotal point of the surgery, which also costs the most. An ideal prosthesis needs appropriate function, rigid fixation, and a long-term durability. It has long been difficult to balance the conformity, constraint, kinematics, and contact stress in the process of prosthetic design. Especially for bone defects, distinguishing revision from primary arthroplasty, there have been many designs. On the basis of the classification system created by Anderson Orthopaedic Research Institute, different treatment options can be adapted to varying degrees of defects. Recently, tantalum cones have been extensively tested in clinic and become an efficient and effective option in joint stabilization at short-term as well as mid-term follow-up (25,26). And there exists an evolution trend that new cones will have the advantage of varying in sizes for accommodating different bone defects and minimizing the further bone loss (27).

As for constraint, rotating hinge prosthesis and constrained condylar prosthesis are two research points (28-31). The comparison between the outcomes of the two has never stopped and the controversy still exists (32,33).

In addition, there are many other designs developed constantly for different use. Some researchers found that the modular offset coupler with femoral stalk in revision improved not only the posterior condyle offset, but also the alignment, compared to the modular straight stalk (34). Others have set the shape and length of the prosthesis as research objects in recent years (35-37). An intraoperatively moulded PMMA cement-prostheses-like spacer with and lower friction, better stability, higher comfort and a better range of motion has been developed (38).

Cluster 2 relates to the adverse effects of revision. The abrasion of articulating spacers happens within 6 weeks, which will do bad to new prosthesis (39). Reinfection outcome has been analyzed systemically, with a similar result in one-stage and two-stage revision (40). And the availability of new biomarkers like procalcitonin and IL-6 were effective in anti-infection around revision, apart from traditional biomarkers (41). A recent study pointed out full functional recovery needs very long time after knee revision surgery and the improvement of gait is limited when compared to the one achieved at the time of spacer implant (42). And another study found that the bone defects will be more serious under the influence of subluxation of articulating antibiotic spacers (43). Nevertheless, the adverse effects not only influence the preoperative initiatives but extends to Medicare policy, medical resource allocation and social economy (44).

Cluster 3 relates to the surgical techniques for revision. For severe patellar bone loss, Hanssen AD put forward a technique of patellar bone-grafting with satisfying short-term and mid-term outcomes (45) and Klein *et al.* reported a gull-wing patellar osteotomy, as a feasible technique in the cases of most severe patellar bone loss (46). Ritschl *et al.*

specifically summarized the techniques for different bone defects of the patella in revision surgery (47).

Tibial tubercle osteotomy is a surgical technique that expands surgical field while retains extensor's function compared with quadriceps snip, has gained popularity in knee revision surgery for many years (48). There have been many attempts aiming at improving it. Ethibond sutures was invented by Deane *et al*. with lower risk of complication than traditional fixation methods (49). Absorbable suture fixation was verified to be a simple and dependable fixation method, which is also affordable (50). Nowadays, the computer-assisted navigation and preoperative software have been introduced to improve the accuracy in revision surgery (51-53).

Cluster 4 relates to the epidemiological characters of revision. Nationwide and worldwide statistical data has been collected to analyze the rate and trends of revision (2,54-56). Recently, a research group established several parametric and non-parametric models to estimate prostheses' survivorship more accurately (57). Another research group analyzed the predictive factors of revision, prosthetic infection and mortality in rheumatoid arthritis patients based on Danish healthcare registers (58). The risk factors of revision have also been analyzed popularly. There were studies supporting that smoking do increases the revision rate after knee arthroplasty (59,60). Glycemic control was given certain attention to reduce the revision rate (61). Obesity is another risk factor which promotes revision with more expenses (62-64). Preoperative opioid use has become a focus associated with higher revision rates recently (65-67).

Cluster 5 relates to the pathophysiology of the revision knee. Knee instability is an important pathological feature in revision cases. Hamilton *et al*. suggested to develop a test to quantize the instability, not according to subjective clinical assessment by patients' symptoms (68). Vince *et al*. explained a simple and universally applicable revision technique that balancing the knee first in flexion and then in extension could optimize motion and stability (69). Stiffness is an uncommon but notable pathological feature after total knee arthroplasty. Revision was previously reported as a relatively better management than the limited approaches such as soft tissue release. But the improvement was modest (70-72). However, there has been a marked improvement in a 2-year clinical outcome of severe stiffness cases, with the use of Genesis and Legion stemmed condylar prostheses (73). In 2016, Donaldson *et al*. even presented a novel technique for improving stiffness, named by "sloppy" revision (74).

However, we realized several potential limitations in this study. Firstly, we only selected original articles and reviews to analyze, so some of the hot spots might be missing. Secondly, the amount of analyzed MeSH terms might affect the result of co-word bi-clustering analysis to some extent, and might not cover the emerging topics of low concern. Thirdly, as the database is constantly updated, the number of articles on knee revision must increase. Therefore, in future research, the bibliometric analysis of knee revision should be combined with more emerging topics and more databases.

Conclusions

With the utilization of the software and websites for bibliometric analysis, we found a growing trend in publications on knee revision and extracted the most contributive researchers, institutions, countries, journals, and most-cited articles worldwide at quantitative level. They have an internalized understanding of this domain and provide principles and guidelines for global researchers as references.

At the qualitative level, through years of practice and discussion, the academic world has reached a consensus on the etiology and indications of revision and many effective clinical techniques have been tested widely and developed continuously in the perioperative period of revision. But there still exists a lot of room for improvement in the solutions for complications and surgical applications, which have also been the hot spots discussed widely these years. Personalized customization with better biomechanical characteristics may become a trend in the design of prostheses for different patients. Minimally invasive and navigation are two attractive concepts and techniques for surgeons, which are excepted to be further developed in the 21st century. With the continuous renewal of surgical instruments and prosthesis design, the surgery is becoming more reasonable and standardized. The utilization of navigation system, which makes it more precise in prosthesis implantation and joint line adjustment, should be included in the future development of revision surgery. Under the background of big-data era, holistic statistical analyses are in progress for individual risk factors and collective epidemiological characters, which can be seemed as another hot spot. And the combination of medicine and economy in analysis is favourable to deploy medical resource more reasonably. Multi-disciplinary integration, which includes medicine, biomechanics, materials science, computer science, epidemiology, and other science, is becoming the

time-trend of hot spots. The hot spots will continue to obtain achievements and our study will provide a powerful reference for the future research and clinical treatment on knee revision.

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Footnote

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