Bibliometric Study of the Most Influential 100 Publications in Vertebral Augmentation Research

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Abstract

Purpose A bibliometric study was conducted to identify and analyze the most influential 100 publications in vertebral augmentation research.

Methods Databases of Web of Science and Pubmed were searched using the key words of ‘percutaneous vertebroplasty’, ‘percutaneous kyphoplasty’, ‘balloon kyphoplasty’, ‘vertebroplasty’, ‘kyphoplasty’ and ‘vertebral augmentation’. The searched publications were arranged by the times of cited per year after excluding the papers not associated with vertebral augmentation closely. The top 100 publications were defined as the most influential papers in this field and analyzed. Collecting data included the journal, the year of publication, the nation of the Corresponding author, the total times of citation, the citation times per year since publication, and the study type of the papers. The evidence levels of the clinical studies were graded between I to V. The systemic reviews and meta-analyses were combined as a specific type.

Results The total citation times of the 100 publications were 27222 and they were cited 18.3 times per year in average. These papers were published in 31 journals in which 13 kinds of journals published more than 2 papers. Corresponding authors came from 17 different nations in which the American authors were the most. The level IV evidence studies were the most as 41 and only 3 papers reached the standards of level I evidence study. The number of the publications decreased obviously after 2009, in which year the two level I evidence publications were published.

Conclusion There are still contrary opinions about vertebral augmentation now even after the publications of the two authoritative studies of level I evidence. New studies should be developed with more deliberated design and longer follow-up, meanwhile the patients should be selected more cautious and the evaluation factors should be included more extensively.

Background

Bibliometric studies refer to the statistical analysis of the most influential publications associated with a specific field or subject. By this method, the researchers can comprehend the subject more thoroughly and grasp the evolution of the subject accurately. Though with several limitations, the number of citation times is still the standard index that most commonly used to represent the influence of publications. Recent years, several bibliometric studies have been published subsequently focusing on some issues from different perspectives, for example kinds of subjects[1–4], different anatomic regions[5, 6], kinds of surgical technologies[7], or special kinds of diseases[8, 9], and even a given territory[10].

Vertebral augmentation is a kind of operation using to restore the strength and stiffness of the vertebrae with fracture caused by tumor or osteoporosis. This kind of technology mainly includes percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP). Many clinic trails found excellent results of vertebral augmentation in pain relief and function restore. Meanwhile some level I evidence publications indicated that PVP and PKP were not prior than conservative treatment when the operations were used to treat osteoporotic vertebral compression fracture (OVCF).

In the current study, the most influential publications about vertebral augmentation include PVP and PKP were analyzed since there were still conflicting opinions about these technologies especially when they were used for the treatment of OVCF. Also, the efforts were attempted for authors to propose some suggestions based on this bibliometric study.

Materials And Methods

In the midmonth of July 2019, the databases of Web of Science and Pubmed were searched using the keywords of ‘percutaneous vertebroplasty’, ‘percutaneous kyphoplasty’, ‘balloon kyphoplasty’, ‘vertebroplasty’, ‘kyphoplasty’ and ‘vertebral augmentation’. The first author and the co-first authors of the current study reviewed the publications separately to exclude the articles which were not associated with PVP or PKP closely, for example the researches about the general treatment principles of osteoporotic fracture or some studies about the properties of bone cement. When there were differences in opinions about some articles, the corresponding author discussed the articles with all authors and made the final decision. Then the articles were arranged by the times of cited per year (total times of citation / years from publication to 2019). The top 100 papers were defined as the most influential publications and analyzed.

Collecting data of a publication included the journal and the year of publication, the nation of the corresponding author, total times of citation, the citation times per year since publication, and the study type. When the publications were clinical studies, the evidence of the study was graded between I to V following the guidelines of J Bone Joint Surg Am. The systemic reviews and meta-analyses were combined as a specific type.

Results

The most influential 100 publications were cited 27222 times totally and every paper was cited 18.3 times per year in average (Table 1). The total citations for a paper ranged from 1354 to 31 times and the times of citation per year ranged from 73.18–9.46. All articles were published in English except one case series report from Galibert [11], which was the first publication introduced PVP. It was published in France indeed but was also cited most frequently as 1354 times by the time of our research. Also, this paper was the only one publication in the top 5 that was not level I or II evidence studies.

Table 1
the 100 most frequently cited publications in the research of vertebral augmentation

rank	publication	year of publication	total citations/year: publication to 2019	total citations
1	A Randomized Trial of Vertebroplasty for Osteoporotic Spinal Fractures.	2009	73.18	805
2	A Randomized Trial of Vertebroplasty for Painful Osteoporotic Vertebral Fractures.	2009	72.45	797
3	Vertebroplasty versus conservative treatment in acute osteoporotic vertebral compression fractures (Vertos II): an open-label randomised trial.	2010	48.1	481
4	Efficacy and safety of balloon kyphoplasty compared with non-surgical care for vertebral compression fracture (FREE): a randomised controlled trial.	2009	44.55	490
5	New technologies in spine: kyphoplasty and vertebroplasty for the treatment of painful osteoporotic compression fractures.	2001	42.11	800
6	Note preliminaire sur le traitement des angiomes vertebraux par vertebroplastie acrylique percutanee. [Preliminary note on the treatment of vertebral angioma by percutaneous acrylic vertebroplasty]	1987	41.03	1354
7	Initial outcome and efficacy of kyphoplasty in the treatment of painful osteoporotic vertebral compression fractures.	2001	40.68	773
8	Vertebroplasty and kyphoplasty: a systematic review of 69 clinical studies.	2006	39.79	557
9	Percutaneous polymethylmethacrylate vertebroplasty in the treatment of osteoporotic vertebral body compression fractures: technical aspects.	1997	35.13	808
10	Percutaneous vertebroplasty for pain relief and spinal stabilization.	2000	32.8	656
11	Percutaneous vertebroplasty with polymethylmethacrylate. Technique, indications, and results.	1998	32.77	721
12	Percutaneous vertebroplasty for osteolytic metastases and myeloma: effects of the percentage of lesion filling and the leakage of methyl methacrylate at clinical follow-up.	1996	30.38	729

rank	publication	year of publication	total citations/year: publication to 2019	total citations
13	Percutaneous vertebroplasty and kyphoplasty for painful vertebral body fractures in cancer patients.	2003	27.18	462
14	Occurrence of new vertebral body fracture after percutaneous vertebroplasty in patients with osteoporosis.	2003	25	425
15	Spinal metastases: indications for and results of percutaneous injection of acrylic surgical cement.	1996	23.88	573
16	Long-term observations of vertebral osteoporotic fractures treated by percutaneous vertebroplasty.	2000	23.85	477
17	The biomechanics of vertebroplasty. The effect of cement volume on mechanical behavior.	2001	23.32	443
18	Balloon kyphoplasty versus non-surgical fracture management for treatment of painful vertebral body compression fractures in patients with cancer: a multicentre, randomised controlled trial.	2011	22.44	202
19	Effects of bone cement volume and distribution on vertebral stiffness after vertebroplasty.	2001	21.89	416
20	Comparison of vertebroplasty and balloon kyphoplasty for treatment of vertebral compression fractures: a meta-analysis of the literature.	2008	21	252
21	Vertebroplasty: cement leakage into the disc increases the risk of new fracture of adjacent vertebral body.	2004	20.5	328
22	Adjacent vertebral failure after vertebroplasty. A biomechanical investigation.	2002	20.44	368
23	Percutaneous vertebroplasty: a developing standard of care for vertebral compression fractures.	2001	19.95	379
24	New fractures after vertebroplasty: adjacent fractures occur significantly sooner.	2006	19.86	278
25	Percutaneous vertebroplasty: state of the art.	1998	18.82	414
26	Percutaneous vertebroplasty compared with optimal pain medication treatment: Short-term clinical outcome of patients with subacute or chronic painful osteoporotic vertebral compression fractures. The VERTOS study.	2007	18.62	242

rank	publication	year of publication	total citations/year: publication to 2019	total citations
27	Incidence of subsequent vertebral fracture after kyphoplasty.	2004	18.31	293
28	The effect of cement augmentation on the load transfer in an osteoporotic functional spinal unit: finite-element analysis.	2003	18.24	310
29	Percutaneous vertebroplasty in the treatment of osteoporotic vertebral compression fractures: an open prospective study.	1999	17.95	377
30	Balloon kyphoplasty and vertebroplasty for vertebral compression fractures: a comparative systematic review of efficacy and safety.	2006	17.57	246
31	Vertebral compression fractures: pain reduction and improvement in functional mobility after percutaneous polymethylmethacrylate vertebroplasty retrospective report of 245 cases.	2003	17.47	297
32	Pulmonary embolism caused by acrylic cement: a rare complication of percutaneous vertebroplasty.	1999	17.05	358
33	Balloon kyphoplasty versus vertebroplasty for treatment of osteoporotic vertebral compression fracture: a prospective, comparative, and randomized clinical study.	2010	17	170
34	Twelve-Months Follow-up in Forty-Nine Patients With Acute/Semiacute Osteoporotic Vertebral Fractures Treated Conservatively or With Percutaneous Vertebroplasty A Clinical Randomized Study.	2010	16.9	169
35	Safety and efficacy of vertebroplasty for acute painful osteoporotic fractures (VAPOUR): a multicentre, randomised, double-blind, placebo-controlled trial.	2016	16.75	67
36	Vertebral Augmentation Involving Vertebroplasty or Kyphoplasty for Cancer-Related Vertebral Compression Fractures: An Economic Analysis.	2016	16.5	66
37	Percutaneous transpedicular vertebroplasty with PMMA: operative technique and early results. A prospective study for the treatment of osteoporotic compression fractures.	2000	16.1	322
38	Leakage of cement in percutaneous transpedicular vertebroplasty for painful osteoporotic compression fractures.	2003	15.41	262

rank	publication	year of publication	total citations/year: publication to 2019	total citations
39	Randomized controlled trial of percutaneous vertebroplasty versus optimal medical management for the relief of pain and disability in acute osteoporotic vertebral compression fractures.	2011	15.33	138
40	Balloon kyphoplasty in the management of vertebral compression fractures: an updated systematic review and meta-analysis.	2007	15	195
41	Vertebroplasty and kyphoplasty for the treatment of vertebral compression fractures: an evidenced-based review of the literature.	2009	14.64	161
42	Comparison of Percutaneous Vertebroplasty and Balloon Kyphoplasty for the Treatment of Single Level Vertebral Compression Fractures: A Meta-analysis of the Literature.	2015	14.6	73
43	Management of acute osteoporotic vertebral fractures: a nonrandomized trial comparing percutaneous vertebroplasty with conservative therapy.	2003	14.59	248
44	Percutaneous vertebroplasty for osteoporotic compression fractures: quantitative prospective evaluation of long-term outcomes.	2002	14.5	261
45	Comparing effects of kyphoplasty, vertebroplasty, and non-surgical management in a systematic review of randomized and non-randomized controlled studies.	2012	14.38	115
46	Biomechanical efficacy of unipedicular versus bipedicular vertebroplasty for the management of osteoporotic compression fractures.	1999	14.38	302
47	Injectable bone cements for use in vertebroplasty and kyphoplasty: state-of-the-art review.	2006	14.07	197
48	Treatment of painful osteoporotic vertebral fractures with percutaneous vertebroplasty or kyphoplasty.	2001	13.79	262
49	Percutaneous vertebroplasty: functional improvement in patients with osteoporotic compression fractures.	2006	13.79	193
50	Kyphoplasty in the treatment of osteolytic vertebral compression fractures as a result of multiple myeloma.	2002	13.78	248

rank	publication	year of publication	total citations/year: publication to 2019	total citations
51	An in vivo comparison of the potential for extravertebral cement leak after vertebroplasty and kyphoplasty.	2002	13.72	247
52	Balloon Kyphoplasty for the Treatment of Acute Vertebral Compression Fractures: 2-Year Results From a Randomized Trial.	2011	13.67	123
53	Load shift of the intervertebral disc after a vertebroplasty: a finite-element study.	2003	13.59	231
54	Percutaneous vertebroplasty compared to conservative treatment in patients with painful acute or subacute osteoporotic vertebral fractures: three-months follow-up in a clinical randomized study.	2009	12.64	139
55	Percutaneous Treatment of Vertebral Compression Fractures A Meta-analysis of Complications.	2009	12.45	137
56	Percutaneous vertebroplasty guided by a combination of CT and fluoroscopy.	1994	12.38	322
57	Early radiographic and clinical results of balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures.	2003	12.35	210
58	Risk factors of new compression fractures in adjacent vertebrae after percutaneous vertebroplasty.	2004	12.13	194
59	A review of complications associated with vertebroplasty and kyphoplasty as reported to the Food and Drug Administration medical device related web site.	2004	12.13	194
60	Management of pulmonary cement embolism after percutaneous vertebroplasty and kyphoplasty: a systematic review of the literature.	2009	12.09	133
61	Clinical outcomes after acute osteoporotic vertebral fractures: a 2-year non-randomised trial comparing percutaneous vertebroplasty with conservative therapy.	2006	11.93	167
62	Risk factors predicting the new symptomatic vertebral compression fractures after percutaneous vertebroplasty or kyphoplasty.	2012	11.88	95

rank	publication	year of publication	total citations/year: publication to 2019	total citations
63	An ex vivo biomechanical evaluation of an inflatable bone tamp used in the treatment of compression fracture.	2001	11.84	225
64	Pulmonary embolism of polymethyl methacrylate during percutaneous vertebroplasty and kyphoplasty.	2004	11.81	189
65	Percutaneous vertebroplasty for spinal metastases: complications.	2006	11.79	165
66	The dynamic mobility of vertebral compression fractures.	2003	11.47	195
67	Effect of vertebroplasty on pain relief, quality of life, and the incidence of new vertebral fractures: A 12-month randomized follow-up, controlled trial.	2012	11.38	91
68	Treatment of painful vertebral fractures by kyphoplasty in patients with primary osteoporosis: a prospective nonrandomized controlled study.	2005	11.33	170
69	The effect of vertebral body percentage fill on mechanical behavior during percutaneous vertebroplasty.	2003	11.18	190
70	Prospective evaluation of pain relief in 100 patients undergoing percutaneous vertebroplasty: results and follow-up.	2002	11.11	200
71	Cement leakage in percutaneous vertebroplasty for osteoporotic vertebral compression fractures: identification of risk factors.	2011	11.11	100
72	Vertebroplasty, first 1000 levels of a single center: Evaluation of the outcomes and complications.	2007	11	143
73	Balloon kyphoplasty: one-year outcomes in vertebral body height restoration, chronic pain, and activity levels.	2003	11	187
74	Balloon kyphoplasty is effective in deformity correction of osteoporotic vertebral compression fractures.	2005	10.93	164
75	Pulmonary Cement Embolism after Percutaneous Vertebroplasty in Osteoporotic Vertebral Compression Fractures: Incidence, Characteristics, and Risk Factors.	2009	10.82	119

rank	publication	year of publication	total citations/year: publication to 2019	total citations
76	High-viscosity cement significantly enhances uniformity of cement filling in vertebroplasty: an experimental model and study on cement leakage.	2006	10.79	151
77	Percutaneous vertebroplasty for severe osteoporotic vertebral body compression fractures.	2002	10.72	193
78	Meta-Analysis of Vertebral Augmentation Compared With Conservative Treatment for Osteoporotic Spinal Fractures.	2013	10.71	75
79	The risk of new osteoporotic vertebral compression fractures in the year after percutaneous vertebroplasty.	2006	10.64	149
80	Biomechanical evaluation of a new bone cement for use in vertebroplasty.	2000	10.5	210
81	Percutaneous vertebroplasty.	2003	10.47	178
82	Dose-dependent epidural leakage of polymethylmethacrylate after percutaneous vertebroplasty in patients with osteoporotic vertebral compression fractures.	2002	10.39	187
83	CIRSE Guidelines on Percutaneous Vertebral Augmentation.	2017	10.33	31
84	Primary and secondary osteoporosis' incidence of subsequent vertebral compression fractures after kyphoplasty.	2004	10.31	165
85	Cement leakage during vertebroplasty: an underestimated problem?	2005	10.27	154
86	Mortality Risk for Operated and Nonoperated Vertebral Fracture Patients in the Medicare Population.	2011	10.11	91
87	Efficacy and safety of balloon kyphoplasty in the treatment of vertebral compression fractures: a systematic review.	2006	10.07	141
88	Augmentation of mechanical properties in osteoporotic vertebral bones–a biomechanical investigation of vertebroplasty efficacy with different bone cements.	2001	10.05	191
89	The effects of cement volume on clinical outcomes of percutaneous vertebroplasty.	2006	9.93	139

rank	publication	year of publication	total citations/year: publication to 2019	total citations
90	Percutaneous transpedicular polymethylmethacrylate vertebroplasty for the treatment of spinal compression fractures.	2001	9.89	188
91	Biomechanical comparison of unipedicular versus bipedicular kyphoplasty.	2005	9.8	147
92	Percutaneous vertebroplasty for osteoporotic compression fracture: multivariate study of predictors of new vertebral body fracture.	2006	9.71	136
93	A Randomized Trial Comparing Balloon Kyphoplasty and Vertebroplasty for Vertebral Compression Fractures due to Osteoporosis.	2014	9.67	58
94	Balloon kyphoplasty for symptomatic vertebral body compression fractures results in rapid, significant, and sustained improvements in back pain, function, and quality of life for elderly patients.	2006	9.64	135
95	Balloon kyphoplasty versus percutaneous vertebroplasty in treating osteoporotic vertebral compression fracture: grading the evidence through a systematic review and meta-analysis.	2012	9.63	77
96	Percutaneous balloon kyphoplasty for the correction of spinal deformity in painful vertebral body compression fractures.	2002	9.61	173
97	Percutaneous vertebroplasty for osteoporotic vertebral compression fracture.	2015	9.6	48
98	Comparative Efficacy and Tolerability of Three Treatments in Old People with Osteoporotic Vertebral Compression Fracture: A Network Meta-Analysis and Systematic Review.	2015	9.6	48
99	Percutaneous vertebroplasty and balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures and osteolytic tumours.	2005	9.6	144
100	Percutaneous vertebral augmentation: an elevation in adjacent-level fracture risk in kyphoplasty as compared with vertebroplasty.	2007	9.46	123
total			18.3	27222

31 journals were involved in our research among which 13 publishing more than 2 papers. *Spine* published most papers as 24 (Table 2), succeed with *European Spine Journal* and *American Journal of Neuroradiology* both as 10 articles. General medicine journals were the most as 7 and orthopedic journals

included specialist journals of spine were 5 as many as neurosurgery and radiology. Other involved journals included oncology (2), interventional radiology (2), rheumatology (2), pain physician (1), clinical imaging (1), and osteoporosis (1).

Table 2
Journals of the publications

No	journal	publications	No	journal	publications
1	Spine	24	17	The American journal of medicine	1
2	American journal of neuroradiology	10	18	Ontario health technology assessment series	1
3	European spine journal	10	19	Journal of biomedical materials research. Part B, Applied biomaterials	1
4	Radiology	8	20	Journal of clinical oncology	1
5	Journal of bone and mineral research	6	21	Clinical imaging	1
6	Lancet oncology	4	22	Pain physician	1
7	Journal of vascular and interventional radiology	4	23	Journal of neurosurgery-Spine	1
8	Spine journal	4	24	Neurosurgery	1
9	Journal of neurosurgery	3	25	Neuro-Chirurgie	1
10	The Journal of bone and joint surgery. British volume	3	26	Rheumatology	1
11	New England journal of medicine	2	27	The Journal of rheumatology	1
12	Cardiovascular and interventional radiology	2	28	American journal of roentgenology	1
13	Osteoporosis international	2	29	Radiographics	1
14	Cochrane database of systematic reviews	1	30	Radiologic clinics of North America	1
15	The Medical journal of Australia	1	31	Acta radiological	1
16	Plos one	1	**total**		**100**

Corresponding authors came from 17 different nations, among which the number of the American authors was the most as 46 (Table 3), followed by France (11). The authors of Australia, Switzerland and Korea were as many as 5.

Table 3
the nations of correspond authors

country	publications	country	publications
USA	46	Canada	3
France	11	Belgium	2
Australia	5	Spain	3
Switzerland	5	Denmark	2
Korea	5	Greece	1
China	4	Japan	1
Netherlands	3	Iran	1
UK	3	Singapore	1
Germany	4	**total**	**100**

As for the level evidence of the clinical researches, 3 studies met the standard of level I evidence and 13 publications were level II. The number of basic studies was 13, the systemic reviews and meta-analyses were included as 15. Others were clinical studies of level III (4), IV(41) and V(11) evidence publications. Naturally the level IV evidence studies were the most in the current research. Most publications were distributed in the years of 2000–2009 as 72 papers and after 2009 the numbers of all kinds of publications decreased obviously (Fig. 1).

Discussion

In 1987, Galibert [11] introduced that certain vertebral angiomas could be destructed by the operation of percutaneous intrasomatic injection of acrylic cement and the consolidation of vertebral column could be obtained meanwhile. Through there were only 7 cases in the research and the period of follow-up was only 2 years, the authors confirmedly believed that this technology was an ideal alternative for the treatment of tumors in the vertebrate. This article was seen as the symbol of the appearance of PVP and it was cited the most frequently even though the article was published in France indeed. 10 yeas later, Jensen [12] published the research of PVP treating the OVCFs and concluded that the technology was a valuable method which providing immediate pain relief and early mobilization in appropriate patients. This article was cited the second most frequently judging by total citation times until now.

After 1997, the technology of PVP and PKP were spreading universally for the treatment of OVCF and many researches were implemented to explore its indications, complications, prognosis, and the indeed

results especially when comparing with conservative methods. Naturally, some prospective studies and randomized trials were proceeded and some confusing results were emerged. For example, the randomized trial of Kallmes [13] published in 2009, which was the third frequently judging by total citation times.

In 2009, The *New England Journal of Medicine* published two RCTs about vertebroplasty in the same issue. The times of cited per year of these two publications were the top 2 in our research. In the first article, Buchbinder [14] performed a multicenter, randomized, double-blind, placebo-controlled trial to compare vertebroplasty and sham procedure in 78 patients older than 50 years with painful osteoporotic vertebral fractures whose duration were less than 12 months and unhealed. The outcomes included overall pain, pain at night and at rest, physical functioning, quality of life, and perceived improvement at 1 week, 1, 3 and 6 months. The authors concluded that vertebroplasty did not received significant advantage in all measured outcomes at all time points. Also, there were no differences in the incident of vertebral fractures after operations. In this study, patients were randomly assigned to different groups before entering the operation room. For the patients in sham intervention group, all procedures were similar to the PVP group until the needle was inserted to the lamina. Then gentle tapping was also proceeded to simulate the manipulation of PVP.

In the second study, Kallmes [13] compared vertebroplasty with the simulated procedure without cement for osteoporotic spinal fractures in 131 patients and the follow-up period was 3 months. In their multicenter trial, the modified Roland-Morris Disability Questionnaire (RDQ) and ratings of average pain intensity were used as primary outcomes. The conclusions indicated that patients in vertebroplasty group and control group got similar improvements and there were no differences between the two groups. In this study, authors randomized the patients to different groups even after the anesthesia of skin and subcutaneous tissues. The blind methods were realized by verbal and physical cues for example the pressure on the back and the odor similar to PMMA.

These two articles were so important and converted the traditional opinions about PVP that they were the top 2 most frequently cited publications judged by annual average citations in our research. Many surgeons and physicians turned to propose conservative opinions to these kinds of operations, especially when they were used to treat osteoporotic spinal fractures. Based on these two articles which were seen as level I evidences and other three level II evidences [15–17], the American Academy of Orthopaedic Surgeons (AAOS) [18] recommended strongly against the vertebroplasty for the patients with OVCF on imaging with correlating clinical signs and the kyphoplasty was recommended weakly to the same patients. The numbers of publications declined so rapidly after 2009 that obvious turnoffs were seen in our analysis for nearly all kinds of studies, maybe for the reasons of the results and suggestions above.

Still, there were contrary opinions. Another level I evidence in our research was the study of Clark [19] in 2016, almost the most recent paper in our research. There were 120 patients with acute OVCFs that less than 6 weeks in the study. Researchers simulated the vertebroplasty by doing all the same procedures until the short needle arriving the periosteum, then skin pressure and tapping on the needle were imposed

to mimic vertebroplasty. Other factors were also used such as the conversation about PMMA mixing and injection suggestion. Authors concluded that vertebroplasty was superior than conservative treatment for the patients with OVCFs less than 6 weeks.

All these level I evidence trials used delicate design and great effort to ensure the ‘blindness’. And this was also the most difficult point in the evaluation of PVP/PKP with conservative treatments of OVCF. Most of the publications were graded as II evidence because of the absence of ‘blindness’ in the current study. In these level II evidence publications, most still compared PVP [17, 20–22] or PKP [23–27] with non-surgical treatments. Bewilderingly, nearly all the publications of level II evidence studies achieved similar results that these two methods were suitable for the treatments of VCF than conservative treatment. Even a publication of nearly neutral opinion indicated that PKP can relieve the pain more rapidly than conservative treatment [15]. Another two publications compared PVP with PKP, one recommended PVP because of the higher costs of PKP [28]. The other one concluded that the results of PVP and PKP were similar, meanwhile the procedure duration of PVP was shorter, but PKP had fewer cement leakages and longer fracture-free survival [29]. The last one of level II evidence publication compared PKP with conservative treatment in the VCF patients with cancer and recommended PKP certainly [30].

In the currently study of us, the systemic reviews and meta-analyses were combined as a specific kind of publication. There were 15 publications in this kind, published all after 2000 and most (10/15) was after 2009. Maybe this distribution indicated the authors’ wondering about the question of ‘Is It Time to Stop (or Pause) Vertebral Augmentation?’ [31]

Systematic reviews by different authors recognized the rapid pain relief of PVP and PKP generally, meanwhile recommended that comparative, blinded, randomized clinical trials should be produced and standardized evaluative methods should be adopted since there were no enough evidences to support the safeness and effectiveness of these technologies [32–37]. Some authors also mentioned the information to the patients about the benefits and potential harms before operations [38]. Taylor [39] compared PKP with PVP and concluded that both procedures could achieve benefits in the treatment of OVCF, and PKP appeared better in the adverse event profile. Other systematic reviews focused on the complications such as pulmonary cement embolism [40]. Contrary to these cautious commends in the treatment of OVCF, the applications of PVP and PKP for cancer-related VCFs gained extensive recognitions [41].

As for meta-analyses, Eck [42] compared PVP and PKP using the method of meta-analysis in 2008 and concluded that both methods could provide improvement in VAS pain scores, meanwhile PVP had a more significant improvement and also a greater risk of cement leakage and new fracture. Wang [43] got similar result in the meta-analysis comparing PVP and PKP for the treatment of single level VCF. Lee [44] considered PVP/PKP as minimally invasive procedures for VCF and evoked future prospective studies to validate the results. Another meta-analysis of Anderson [45] recommended the cement augmentation in the treatment of symptomatic VCF. Chen [46] also compared PVP, PKP with conservative treatment by the method of Bayesian-framework network meta-analysis in old people with OVCF. The conclusion was that

PVP achieved the best effect of relieve pain, the conservative treatment was associated with the lowest incidence of new fractures and balloon kyphoplasty had the lowest risk of all-cause discontinuation.

12 publications were the basic researches in the current research, most of which were biomechanical studies using cadaveric vertebral bodies [47–54] or the method of finite-element analysis [55–57]. These studies mentioned similar conclusions that the cement augmentation could restore the strength of the affected vertebrae [49] but increase the fracture possibility of the adjacent vertebrae meanwhile. Some technology skills were discussed in these studies. Belkoff [50] tested the effect of tamp treatment used in PKP and confirmed that this technology could restore the height of vertebrae better than PVP. Molloy [51] related the strength and stiffness weakly with the percentage of cement filling volume during PVP. Steinmann [54] compared unipedicular with bipedicular approaches and recommended the former for a comprehensive consideration. The experimental model [58] and cadaveric vertebral bodies [52, 53] were also used to study the property of some special kind of cement or compare different kinds of cements.

Naturally the most clinical studies were level III-V evidence publications include the case-control studis, retrospective comparative studies, case series reports, and reviews. Also, the numbers of these publications decreased obviously after 2009. These studies discussed PVP and PKP from different perspectives and got many results about these two procedures. Nearly all studies were associated with the treatment for OVCF and only 9 were about the using of these operations to treat vertebral fractures with tumor, such as the angioma [11], multiple myeloma [59], or metastases [60] .

Leakage of cement [61–64] and embolism [65, 66] were studied more frequently as the most common complications during or in short time after the operations. Adjacent fractures [67, 68] were the frequently discussed complications in long period.

The period of follow-up in most studies was between 1 to 24 months and the cases were tens to hundreds. The longest period was a cohort study of Edidin [69] at up to 4 years. And this study indicated that the patients in the non-operated cohort had a lower adjusted survival rate than the patients of operation group. Meanwhile the kyphoplasty patients had a lower relative risk of mortality than PVP. It reminded us that longer follow-up might indicate different results about these procedures, especially considering the old patients which were more possibly affected by the OVCF. The cost using in the treatment of OVCF also should be a consideration in the future studies. In 2013, Svedbom [70] performed a cost-effective analysis to compare balloon kyphoplasty, vertebroplasty and non-surgical management for the treatment of acute OVCF. The results revealed that PKP may be a cost-effective strategy for the treatment of OVCF. When thinking about the cost, some extra expenses should be included such as the nursing costs in the period of treatment.

Conclusion

Though the number of publications decreased obviously from 2009 after the publications of the two authoritative level I evidence studies, there are still contrary opinions about PVP and PKP. The procedures are implementing all over the world still now, especially for the treatment of OVCF in old patients. It seems

there will be long roads to exceed for the different opinions to reach a consensus. In these days, PVP and PKP should be produced cautiously including choosing patients strictly and informing the results and potential risks thoroughly to both the patients and their family. Meanwhile, new methods should be explored for further researches which might be more deliberated and objective. With these methods, more patients with different baselines should be selected for longer follow-up, meanwhile the evaluation factors should be more extensive covering relative fields including the treatment results in short and long range, the long-term survival rate, the costs using for the treatment of the patients, and the nursing cost provided by medical institutions or families.

Abbreviations

PVP: Percutaneous vertebroplasty

PKP: Percutaneous kyphoplasty

OVCF: Osteoporotic vertebral compression fracture

RCT: Randomized controlled trial

RDQ: Roland-Morris Disability Questionnaire

AAOS: American Academy of Orthopaedic Surgeons

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions:

WS analyzed and interpreted the article data regarding the percutaneous vertebroplasty and percutaneous, and was the major contributor in writing the manuscript. JN and WS performed the searching and collecting the articles. All authors read and approved the final manuscript.

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Figures

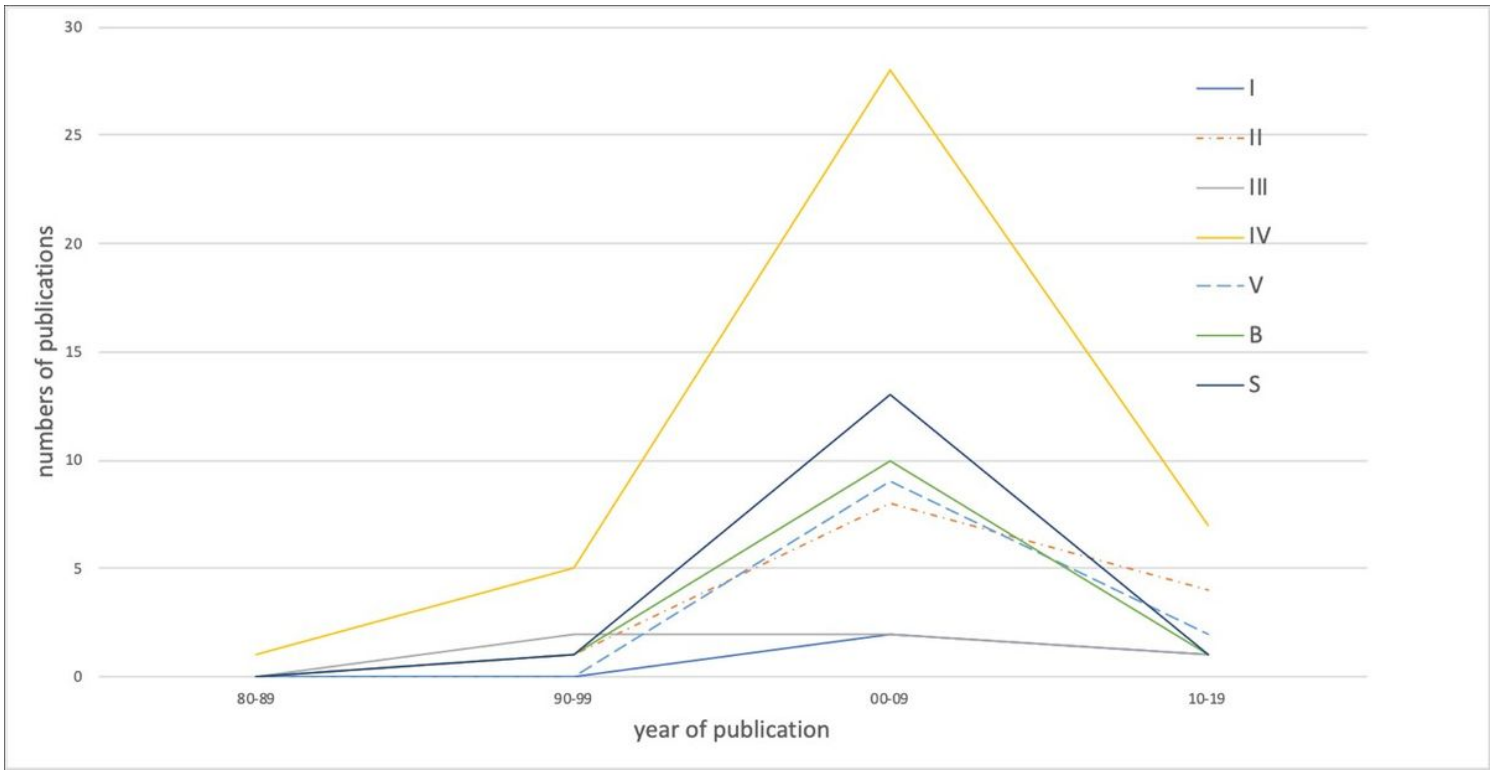

Figure 1

The distribution of different types of publications. I-V refer to the level of evidence for clinical studies. B means to the basic studies and S for the systemic reviews and meta-analyses.