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New insight into the current study of high tibial osteotomy

A bibliometric analysis

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Abstract

Background: To analyze global trends in focus and funding of research related to high tibial osteotomy (HTO) and to identify the 100 most cited articles in this field.

Methods: A Web of Science search was used to identify HTO publications in English-language scientific journals from January 1967 till February 3th, 2021. Results were filtered to the 100 most cited articles by reading the abstract or full-text paper. Information of these articles was recorded for further analysis. The 10 top-cited articles during the last 5 years and the 10 top-cited articles about HTO ranked by average citations per year were selected to predict research trends.

Results: In all, 48 out of the 100 top-cited articles were published between 2000 and 2010. The United States of America was the primary contributor (n = 29) followed by Germany (n = 17) and Japan (n = 11). The total number of citations per article ranged from 65 to 563, median 108, mean 135 (standard deviation = 84). The American Journal of Bone and Joint Surgery accounted for 23 out of the 100 top-cited articles. Koshino T was the most cited author (603 citations). The most frequently highlighted study theme was prognostic research. Patient-based clinical research was the dominant study design (85%). The majority of articles (48 out of 100) were level IV evidence with a mean of 141 (standard deviation = 97) citations. Top-cited articles in the last 5 years focused on open wedge osteotomy.

Conclusion: Technical optimization of open wedge osteotomy has emerged as the main area of research in HTO. More specifically, recent publications focus on the surgical technology, cartilage repair and new fixation devices. Besides, papers with a high level of evidence are needed for the development of HTO.

Abbreviations: ACY = average citations per year, CWHTO = closed wedge HTO, HTO = high tibial osteotomy, KOA = knee osteoarthritis, OA = osteoarthritis, OWHTO = open wedge HTO, SD = standard deviation, TKA = total knee arthroplasty, TNC = total number of citations per article.

Keywords: bibliometric analysis, high tibial osteotomy, research trends

1. Introduction

Osteoarthritis (OA) is a kind of joint degenerative disease with recurrent joint pain and joint dysfunction, which seriously endangers the physical and mental health of middle-aged and elderly patients.[1] The incidence rate of knee osteoarthritis (KOA) is the highest in OA. It is one of the most common OA in clinical practice, and it damages the individual and society most.[2] At present, the treatment of KOA mainly includes total knee arthroplasty (TKA), unicompartmental knee arthroplasty, high tibial osteotomy (HTO), arthroscopic intervention, conservative treatment, etc[3] TKA is one of the most cost-effective orthopedic surgeries with high success rate, mainly for the elderly patients with end-stage knee

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joint, severe joint deformity, and three compartment affected. Clinical studies have shown that TKA has a significant effect in relieving pain, restoring function, and improving quality of life.[4] However, it is not the best option for patients with mild to moderate medial compartment OA, especially for young and active patients with high expectation of motor function recovery. According to a US study,[5] about 1/3 of TKA operations for patients with KOA may have "over treatment," which is obviously worthy of our attention. In recent years, with the continuous promotion of the concept of knee protection, unicompartmental knee arthroplasty and HTO, which are relatively less destructive to human tissues, have attracted more and more attention.

HTO is a surgical operation designed to correct the load-bearing axis of the knee joint and move the load from the medial compartment to the lateral. It can relieve the pain symptoms of the knee joint, improve the joint activity, and then prolong the life of the knee joint. It is one of the main methods for the treatment of anteromedial OA.[6,7] Many scholars further found that[8–10] with the moderate release of medial compartment pressure, the biomechanical environment and effective blood circulation of knee joint have been improved, which promotes the cartilage repair of femoral condyle and tibial plateau degeneration. The femoral condyle and tibial plateau are covered by hyaline cartilage, which produces a similar effect of moderate cartilage regeneration. Rudan et al[11] followed up 85 patients with HTO for 10 years and found that more than half of the patients did not receive TKA again. Khoshbin et al[12] also followed up 2671 patients who received HTO and found that 2/3 of the patients were able to avoid TKA within 10 years after HTO. However, the results of the report on the postoperative effect of HTO are different, which may be related to the severity of KOA before operation, the accuracy of correction angle, postoperative functional exercise, patient age, BMI, gender, operation mode, and fixation device materials.[13–15] The recent increase in the number of publications concerning HTO reflects that this procedure still draws worldwide attention and the number of patients with KOA is globally rising.

Bibliometric analysis refers to the quantitative analysis of published articles in subjects of interest by means of statistics and mathematics.[16] Bibliometrics integrates mathematics, statistics, and philology. It is a comprehensive knowledge system focusing on quantification. It is characterized by objectivity, quantification, and modeling. At present, it has been widely used in macro observation and consideration of various fields and disciplines.[17,18] With the help of bibliometrics, we can objectively evaluate the position of our research in the major research direction, and also point out the direction for further research. To the best of our knowledge, this is the first bibliometric analysis for HTO. The purpose of this study was to identify and analyze the 100 most cited articles in the field of HTO and to provide a current and prospective view on the specific focus of international HTO research.

2. Materials and Methods

On February 3th, 2021, a retrospective evaluation of publicly available data using the database Web of Science Core Collection, BIOSIS Citation Index, KCI-Korean Journal Database, MEDLINE, Russian Science Citation Index, and SciELO Citation Index was used to retrieve all English-language articles via the Web of Science provided by Thomson Reuters (Philadelphia, PA).

2.1. Identification of the 100 most cited articles

Using the search terms "high tibial osteotomy" and "proximal tibial osteotomy", a total of 4539 hits was obtained. Next, papers were selected by article type: articles and clinical trials were included for analysis, and papers that were not based on original patient data (reviews, meta-analyses, systematic reviews, and guidelines) were excluded, leaving 4318 hits. Exclusion of results with <60 citations left 308 hits. The title and abstract, or full text if needed, were reviewed by CW and WZ using the following inclusion criteria: biomechanical rationale or basic laboratory or animal research related to any aspect of HTO; the surgical indication, surgical technique, internal fixation method of HTO; articles investigating clinical therapeutic, prognostic, epidemiological studies of HTO. Disagreements between investigators were discussed with a third reviewer (TH, a senior orthopedic surgeon). Applying these inclusion criteria, 112 accepted publications remained and were ranked based on their citation number in descending order. The top 100 most cited articles were selected for subsequent analysis (Fig. 1).

2.2. Information extraction

For each article, the following information was extracted: first author, country of origin, year of publication, research theme, level of evidence, keywords, 7citations per article (TNC), and average citations per year (ACY).

2.3. Statistical analysis

General data are expressed as median or mean (standard deviation [SD]). Kruskal–Wallis test was used for comparisons between groups. An α level of 0.05 ($P < .05$) was considered statistically significant. Time-dependency was analyzed using the Mann–Kendall trend test. Statistical analysis was performed using SPSS V20.0 (IBM Corporation, Armonk, NY). UCINET 6 for Windows, version 6.212 (Harvard, MA, USA), was used to perform analysis for the degree of centrality.

The bibliometric software Vosviewer_1.6.15 was utilized for analyzing keywords of literatures published in the last 5 years. "Overlay visualization" was adopted to identify important keywords and give relative impact to each keyword based on its calculated value. The keywords could be considered as substitutions of scientific ideas and be used to construct a co-occurrence network.

2.4. Identification of the 10 most cited articles during the last 5 years

Using the search term "TS = ('high tibial osteotomy' or 'proximal tibial osteotomy') and PY = (2022 OR 2021 OR 2020 OR 2019 OR 2018)," a total of 278 results were obtained. The results were sorted in descending order according to TNC. Inclusion and exclusion following the aforementioned criteria were used to select the top 10 most cited articles since 2018

3. Results

The list of 100 TNCs is shown in Table 1. TNC ranged from 65 to 563, median 108, mean 135 (SD 84). A minority of papers (11) were cited more than 200 times. We found that the top-cited article (TNC = 563) was a long-term follow-up study on ninety-three knees after open wedge HTO (OWHTO), published in the Journal of bone and joint surgery American Volume in1987 by Hernigou et al. Citations were mainly attributed to research on orthopedics (n = 367), surgery (n = 225), and sport sciences (n = 187). Less than a quarter of the articles (n = 22) were published before 1990. Only 16 articles were published between 1990 and 2000 and the vast majority (n = 62) of articles were published after 2000 (Fig. 2). The particular year with the most number of articles was 2004 (n = 8). The Mann–Kendall trend test showed an increasing trend between citation density and time (P = 1.342E-10, Z = 6.4223) (Fig. 3).

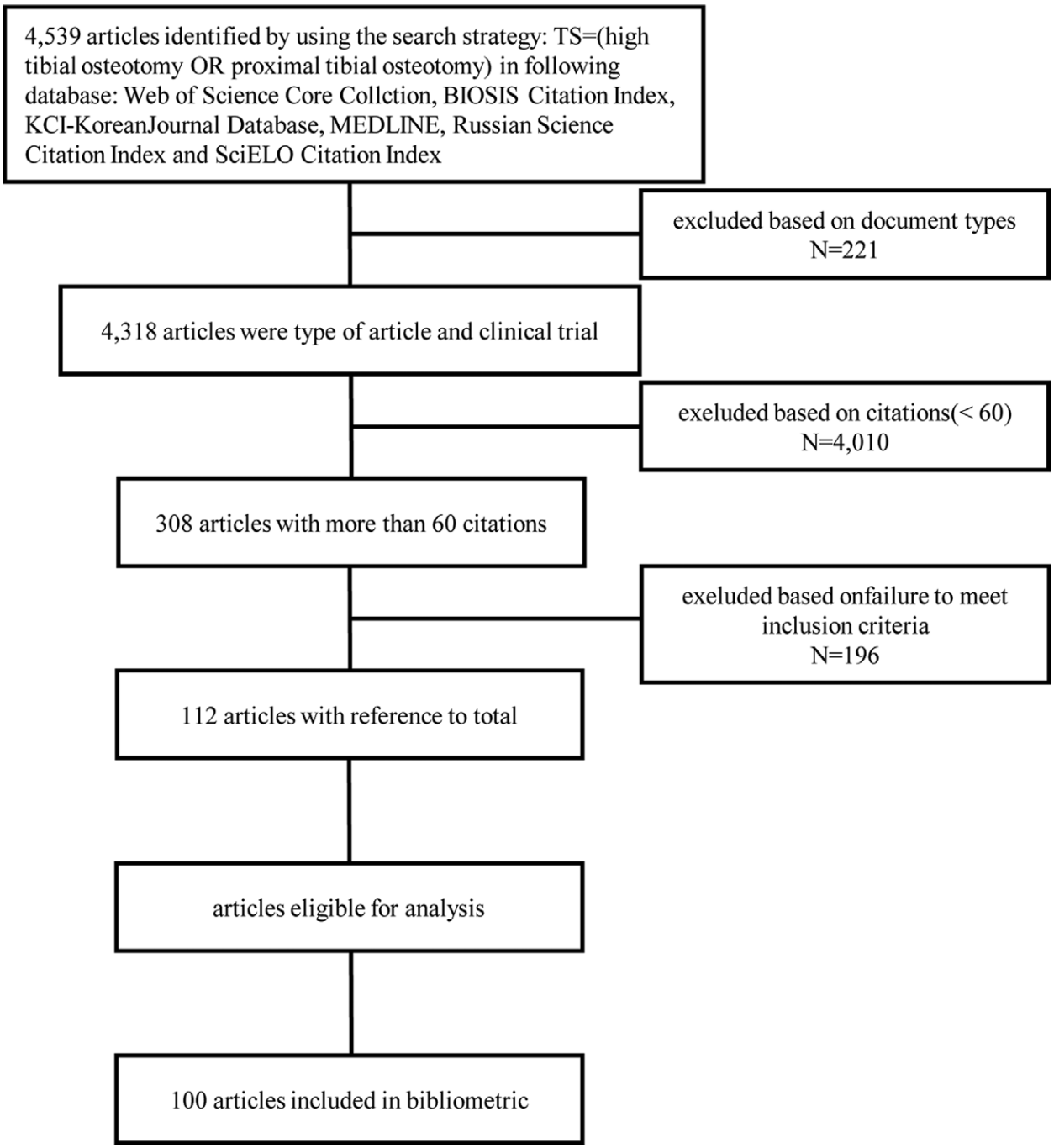

Figure 1. The allocation process of the top 100 articles.

3.1. Country and author

Within the top 100 cited articles list, there were 17 countries of origin. The majority of articles (29%) originated from the U.S, followed by Germany (n = 17) and Japan (n = 11). Countries of origin contributing ten or fewer articles are illustrated in Figure 4. USA based articles were mainly published in the Journal of Bone and Joint Surgery American Volume. Twelve reappearing first authors and their basic information are listed in Table S1, Supplementary Digital Content 1, http://links.lww.com/MD/H165. Koshino T, from Japan, could be assigned the highest number of first author hits. All of his publications were clinical experience-based, mainly regarding the improvement of HTO surgical methods, with a total of 603 citations.

3.2. Type and theme of research

The top 100 most cited articles were categorized by article type (Fig. 5). A large number of articles (n = 85) were based on patients, as clinical research. Of which, only 8 were designed as randomized controlled trials, while the number of articles carrying out reported survivorship analysis, retrospective study, and prospective study were n = 17, n = 17, n = 9, respectively. The remaining article types were laboratory studies (n = 15). Then, the top 100 HTO articles were sorted into six main topics (Fig. 6A). Most articles on the list were related to prognostic research (n = 32). The most frequent subcategories were long-term follow-up (n = 7), prognostic factors (n = 8), and postoperative complications (n = 5). Surgical methods and materials and surgical indications each accounted for a quarter. The remaining

Table 1

List of the 100 top-cited articles in high tibial osteotomy.

Rank	Article	Citations
1	Hernigou, P., Medevielle, D., Debeyre, J. & Goutallier, D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. The Journal of Bone and Joint Surgery. American volume 69, 332–354 (1987).	536
2	Coventry, M. B., Ilstrup, D. M. & Wallrichs, S. L. Proximal tibial osteotomy. A critical long-term study of eighty-seven cases. The Journal of Bone and Joint Surgery. American volume 75, 196–201, doi:10.2106/00004623-199302000-00006 (1993).	444
3	Fujisawa, Y., Masuhara, K. & Shiomi, S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. The Orthopedic Clinics of North America 10, 585–608 (1979).	429
4	Insall, J. N., Joseph, D. M. & Msika, C. High tibial osteotomy for varus gonarthrosis. A long-term follow-up study. The Journal of Bone and Joint Surgery. American volume 66, 1040–1048, doi:10.2106/00004623-198466070-00010 (1984).	427
5	Prodromos, C. C., Andriacchi, T. P. & Galante, J. O. A relationship between gait and clinical changes following high tibial osteotomy. The Journal of Bone and Joint Surgery. American volume 67, 1188–1194, doi:10.2106/00004623-198567080-00007 (1985).	329
6	Lobenhoffer, P. & Agneskirchner, J. D. Improvements in surgical technique of valgus high tibial osteotomy. Knee Surgery Sports Traumatology Arthroscopy 11, 132–138, doi:10.1007/s00167-002-0334-7 (2003).	307
7	Dugdale, T. W., Noyes, F. R. & Styer, D. Preoperative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. Clinical Orthopaedics and Related Research, 248–264 (1992).	270
8	Staubli, A. E., De Simoni, C., Babst, R. & Lobenhoffer, P. TomoFix: a new LCP-concept for open wedge osteotomy of the medial proximal tibia – early results in 92 cases. Injury-International Journal of the Care of the Injured 34, 55-62, doi:10.1016/j.injury.2003.09.025 (2003).	242
9	Naudie, D., Bourne, R. B., Rorabeck, C. H. & Bourne, T. J. Survivorship of the high tibial valgus osteotomy – A 10-to 22-year followup study. Clinical Orthopaedics and Related Research, 18-27 (1999).	230
10	Sprenger, T. R. & Doerzbacher, J. E. Tibial osteotomy for the treatment of varus gonarthrosis – Survival and failure analysis to twenty-two years. Journal of Bone and Joint Surgery-American Volume 85A, 469–474, doi:10.2106/00004623-200303000-00011 (2003).	227
11	Wong, K. L. et al Injectable Cultured Bone Marrow-Derived Mesenchymal Stem Cells in Varus Knees With Cartilage Defects Undergoing High Tibial Osteotomy: A Prospective, Randomized Controlled Clinical Trial With 2 Years' Follow-up. Arthroscopy-the Journal of Arthroscopic and Related Surgery 29, 2020–2028, doi:10.1016/j.arthro.2013.09.074 (2013).	201
12	Noyes, F. R., Barber-Westin, S. D. & Hewett, T. E. High tibial osteotomy and ligament reconstruction for varus angulated anterior cruciate ligament-deficient knees. American Journal of Sports Medicine 28, 282–296, doi:10.1177/03635465000280030201 (2000).	198
13	Marti, C. B., Gautier, E., Wachtl, S. W. & Jakob, R. P. Accuracy of frontal and sagittal plane correction in open-wedge high tibial osteotomy. Arthroscopy-the Journal of Arthroscopic and Related Surgery 20, 366–372, doi:10.1016/j.arthro.2004.01.024 (2004).	194
14	Agneskirchner, J. D., Hurschler, C., Stukenborg-Colsman, C., Imhoff, A. B. & Lobenhoffer, P. Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees – Winner of the AGA-DonJoy Award 2004. Archives of Orthopaedic and Trauma Surgery 124, 575–584, doi:10.1007/s00402-004-0728-8 (2004).	184
15	Koshino, T., Murase, T. & Saito, T. Medial opening-wedge high tibial osteotomy with use of porous hydroxyapatite to treat medial compartment osteoarthritis of the knee. Journal of Bone and Joint Surgery-American Volume 85A, 78-85, doi:10.2106/00004623-200301000-00013 (2003).	179
16	Billings, A., Scott, D. F., Camargo, M. P. & Hofmann, A. A. High tibial osteotomy with a calibrated osteotomy guide, rigid internal fixation, and early motion – Long-term follow-up. Journal of Bone and Joint Surgery-American Volume 82A, 70-79, doi:10.2106/00004623-200001000-00009 (2000).	173
17	Brinkman, J. M. et al Osteotomies around the knee patient selection, stability of fixation and bone healing in high tibial osteotomies. Journal of Bone and Joint Surgery-British Volume 90B, 1548–1557, doi:10.1302/0301-620x.90b12.21198 (2008).	172
18	Akizuki, S., Shibakawa, A., Takizawa, T., Yamazaki, I. & Horiuchi, H. The long-term outcome of high tibial osteotomy – A ten- to 20-year follow-up. Journal of Bone and Joint Surgery-British Volume 90B, 592–596, doi:10.1302/0301-620x.90b5.20386 (2008).	170
19	Windsor, R. E., Insall, J. N. & Vince, K. G. Technical considerations of total knee arthroplasty after proximal tibial osteotomy. The Journal of Bone and Joint Surgery. American volume 70, 547–555, doi:10.2106/00004623-198870040-00011 (1988).	170
20	Agneskirchner, J. D., Hurschler, C., Wrann, C. D. & Lobenhoffer, P. The effects of valgus medial opening wedge high tibial osteotomy on articular cartilage pressure of the knee: A biomechanical study. Arthroscopy-the Journal of Arthroscopic and Related Surgery 23, 852–861, doi:10.1016/j.arthro.2007.05.018 (2007).	165
21	Miniaci, A., Ballmer, F. T., Ballmer, P. M. & Jakob, R. P. Proximal tibial osteotomy. A new fixation device. Clinical Orthopaedics and Related Research, 250–259 (1989).	165
22	Wang, J. W., Kuo, K. N., Andriacchi, T. P. & Galante, J. O. The influence of walking mechanics and time on the results of proximal tibial osteotomy. The Journal of Bone and Joint Surgery. American volume 72, 905–909, doi:10.2106/00004623-199072060-00017 (1990).	162
23	Noyes, F. R., Goebel, S. X. & West, J. Opening wedge tibial osteotomy – The 3-triangle method to correct axial alignment and tibial slope. American Journal of Sports Medicine 33, 378–387, doi:10.1177/0363546504269034 (2005).	152
24	Spahn, G. Complications in high tibial (medial opening wedge) osteotomy. Archives of Orthopaedic and Trauma Surgery 124, 649–653, doi:10.1007/s00402-003-0588-7 (2004).	152
25	Noyes, F. R., Barber, S. D. & Simon, R. High tibial osteotomy and ligament reconstruction in varus angulated, anterior cruciate ligament-deficient knees. A two- to seven-year follow-up study. The American Journal of Sports Medicine 21, 2-12, doi:10.1177/036354659302100102 (1993).	151

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Table 1

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Rank	Article	Citations
26	Brouwer, R. W., Bierma-Zeinstra, S. M. A., van Raaij, T. M. & Verhaar, J. A. N. Osteotomy for medial compartment arthritis of the knee using a closing wedge or an opening wedge controlled by a Puddu plate – A one-year randomised, controlled study. Journal of Bone and Joint Surgery-British Volume 88B, 1454–1459, doi:10.1302/0301-620x.88b11.17743 (2006).	144
27	Floerkemeier, S., Staubli, A. E., Schroeter, S., Goldhahn, S. & Lobenhoffer, P. Outcome after high tibial open-wedge osteotomy: a retrospective evaluation of 533 patients. Knee Surgery Sports Traumatology Arthroscopy 21, 170–180, doi:10.1007/s00167-012-2087-2 (2013).	142
28	Agneskirchner, J. D., Freiling, D., Hurschler, C. & Lobenhoffer, P. Primary stability of four different implants for opening wedge high tibial osteotomy. Knee Surgery Sports Traumatology Arthroscopy 14, 291–300, doi:10.1007/s00167-005-0690-1 (2006).	142
29	Insall, J., Shoji, H. & Mayer, V. High tibial osteotomy. A five-year evaluation. The Journal of Bone and Joint Surgery. American volume 56, 1397–1405, doi:10.2106/00004623-197456070-00008 (1974).	141
30	Dallari, D. et al Enhanced tibial osteotomy healing with use of bone grafts supplemented with platelet gel or platelet gel and bone marrow stromal cells. Journal of Bone and Joint Surgery-American Volume 89A, 2413–2420, doi:10.2106/jbjs.F.01026 (2007).	139
31	Ivarsson, I., Myrnerts, R. & Gillquist, J. High tibial osteotomy for medial osteoarthritis of the knee. A 5 to 7 and 11 year follow-up. The Journal of Bone and Joint Surgery. British volume 72, 238–244 (1990).	139
32	Kettelkamp, D. B., Wenger, D. R., Chao, E. Y. & Thompson, C. Results of proximal tibial osteotomy. The effects of tibiofemoral angle, stance-phase flexion-extension, and medial-plateau force. The Journal of Bone and Joint Surgery. American volume 58, 952–960, doi:10.2106/00004623-197658070-00010 (1976).	139
33	Stoffel, K., Stachowiak, G. & Kuster, M. Open wedge high tibial osteotomy: Biomechanical investigation of the modified Arthrex Steotomy Plate (Puddu Plate) and the TomoFix Plate. Clinical Biomechanics 19, 944–950, doi:10.1016/j.clinbiomech.2004.06.007 (2004).	137
34	Brouwer, R. W., Bierma-Zeinstra, S. M. A., van Koeveringe, A. J. & Verhaar, J. A. N. Patellar height and the inclination of the tibial plateau after high tibial osteotomy – The open versus the closed-wedge technique. Journal of Bone and Joint Surgery-British Volume 87B, 1227–1232, doi:10.1302/0301-620x.87b9.15972 (2005).	131
35	Vainionpaa, S., Laike, E., Kirves, P. & Tiusanen, P. Tibial osteotomy for osteoarthritis of the knee. A five to ten-year follow-up study. The Journal of Bone and Joint Surgery. American volume 63, 938–946, doi:10.2106/00004623-198163060-00011 (1981).	130
36	Miller, B. S., Downie, B., McDonough, E. B. & Wojtys, E. M. Complications After Medial Opening Wedge High Tibial Osteotomy. Arthroscopy-the Journal of Arthroscopic and Related Surgery 25, 639–646, doi:10.1016/j.arthro.2008.12.020 (2009).	128
37	Koshino, T. The treatment of spontaneous osteonecrosis of the knee by high tibial osteotomy with and without bone-grafting or drilling of the lesion. The Journal of Bone and Joint Surgery. American volume 64, 47-58, doi:10.2106/00004623-198264010-00008 (1982).	126
38	Gaasbeek, R. D. A., Toonen, H. G., van Heerwaarden, R. J. & Buma, P. Mechanism of bone incorporation of beta-TCP bone substitute in open wedge tibial osteotomy in patients. Biomaterials 26, 6713–6719, doi:10.1016/j.biomaterials.2005.04.056 (2005).	123
39	Aglietti, P., Buzzi, R., Vena, L. M., Baldini, A. & Mondaini, A. High tibial valgus osteotomy for medial gonarthrosis: a 10- to 21-year study. The Journal of Knee Surgery 16, 21-26 (2003).	120
40	Broughton, N. S., Newman, J. H. & Baily, R. A. Unicompartmental replacement and high tibial osteotomy for osteoarthritis of the knee. A comparative study after 5-10 years' follow-up. The Journal of Bone and Joint Surgery. British volume 68, 447–452 (1986).	119
41	Shelburne, K. B., Kim, H.-J., Sterett, W. I. & Pandy, M. G. Effect of Posterior Tibial Slope on Knee Biomechanics during Functional Activity. Journal of Orthopaedic Research 29, 223–231, doi:10.1002/jor.21242 (2011).	118
42	Scuderi, G. R., Windsor, R. E. & Insall, J. N. Observations on patellar height after proximal tibial osteotomy. The Journal of Bone and Joint Surgery. American volume 71, 245–248, doi:10.2106/00004623-198971020-00011 (1989).	118
43	Coventry, M. B. Proximal tibial varus osteotomy for osteoarthritis of the lateral compartment of the knee. The Journal of Bone and Joint Surgery. American volume 69, 32-38, doi:10.2106/00004623-198769010-00006 (1987).	118
44	Koshino, T., Yoshida, T., Ara, Y., Saito, I. & Saito, T. Fifteen to twenty-eight years' follow-up results of high tibial valgus osteotomy for osteoarthritic knee. Knee 11, 439–444, doi:10.1016/j.knee.2004.03.005 (2004).	117
45	Yasuda, K., Majima, T., Tsuchida, T. & Kaneda, K. A ten- to 15-year follow-up observation of high tibial osteotomy in medial compartment osteoarthrosis. Clinical Orthopaedics and Related Research, 186–195 (1992).	116
46	Koh, Y.-G., Kwon, O.-R., Kim, Y.-S. & Choi, Y.-J. Comparative Outcomes of Open-Wedge High Tibial Osteotomy With Platelet-Rich Plasma Alone or in Combination With Mesenchymal Stem Cell Treatment: A Prospective Study. Arthroscopy-the Journal of Arthroscopic and Related Surgery 30, 1453–1460, doi:10.1016/j.arthro.2014.05.036 (2014).	111
47	Hui, C. et al Long-Term Survival of High Tibial Osteotomy for Medial Compartment Osteoarthritis of the Knee. American Journal of Sports Medicine 39, 64-70, doi:10.1177/0363546510377445 (2011).	111
48	Flecher, X., Parratte, S., Aubaniac, J.-M. & Argenson, J.-N. A. A 12-28-year followup study of closing wedge high tibial osteotomy. Clinical Orthopaedics and Related Research, 91-96, doi:10.1097/01.blo.0000229362.12244.f6 (2006).	111
49	Takeuchi, R. et al Medial Opening Wedge High Tibial Osteotomy With Early Full Weight Bearing. Arthroscopy-the Journal of Arthroscopic and Related Surgery 25, 46-53, doi:10.1016/j.arthro.2008.08.015 (2009).	110
50	Koshino, T., Wada, S., Ara, Y. & Saito, T. Regeneration of degenerated articular cartilage after high tibial valgus osteotomy for medial compartmental osteoarthritis of the knee. Knee 10, 229–236, doi:10.1016/s0968-0160(03)00005-x (2003).	110

(Continued)

Table 1

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Rank	Article	Citations
51	Takeuchi, R. et al Fractures Around the Lateral Cortical Hinge After a Medial Opening-Wedge High Tibial Osteotomy: A New Classification of Lateral Hinge Fracture. Arthroscopy-the Journal of Arthroscopic and Related Surgery 28, 85-94, doi:10.1016/j.arthro.2011.06.034 (2012).	106
52	Holden, D. L., James, S. L., Larson, R. L. & Slocum, D. B. Proximal tibial osteotomy in patients who are fifty years old or less. A long-term follow-up study. The Journal of Bone and Joint Surgery. American volume 70, 977–982, doi:10.2106/00004623-198870070-00004 (1988).	106
53	Shoji, H. & Insall, J. High tibial osteotomy for osteoarthritis of the knee with valgus deformity. The Journal of Bone and Joint Surgery. American volume 55, 963-973, doi:10.2106/00004623-197355050-00005 (1973).	106
54	Stukenborg-Colsman, C., Wirth, C. J., Lazovic, D. & Wefer, A. High tibial osteotomy versus unicompartmental joint replacement in unicompartmental knee joint osteoarthritis: 7-10-year follow-up prospective randomised study. Knee 8, 187-194, doi:10.1016/s0968-0160(01)00097-7 (2001).	104
55	Niemeyer, P. et al Open-Wedge Osteotomy Using an Internal Plate Fixator in Patients With Medial-Compartment Gonarthritis and Varus Malalignment: 3-Year Results With Regard to Preoperative Arthroscopic and Radiographic Findings. Arthroscopy-the Journal of Arthroscopic and Related Surgery 26, 1607–1616, doi:10.1016/j.arthro.2010.05.006 (2010).	101
56	Akizuki, S., Yasukawa, Y. & Takizawa, T. Does arthroscopic abrasion arthroplasty promote cartilage regeneration in osteoarthritic knees with eburnation? A prospective study of high tibial osteotomy with abrasion arthroplasty versus high tibial osteotomy alone. Arthroscopy-the Journal of Arthroscopic and Related Surgery 13, 9-17, doi:10.1016/s0749-8063(97)90204-8 (1997).	101
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58	Maquet, P. Valgus osteotomy for osteoarthritis of the knee. Clinical Orthopaedics and Related Research, 143–148 (1976).	100
59	W-Dahl, A., Robertsson, O. & Lidgren, L. Surgery for knee osteoarthritis in younger patients. Acta Orthopaedica 81, 161–164, doi:10.3109/17453670903413186 (2010).	99
60	Hankemeier, S. et al Navigated open-wedge high tibial osteotomy: advantages and disadvantages compared to the conventional technique in a cadaver study. Knee Surgery Sports Traumatology Arthroscopy 14, 917-921, doi:10.1007/s00167-006-0035-8 (2006).	99
61	Caton, J. H. & Dejour, D. Tibial tubercle osteotomy in patello-femoral instability and in patellar height abnormality. International Orthopaedics 34, 305-309, doi:10.1007/s00264-009-0929-4 (2010).	96
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63	El-Azab, H., Glabgly, P., Paul, J., Imhoff, A. B. & Hinterwimmer, S. Patellar Height and Posterior Tibial Slope After Open- and Closed-Wedge High Tibial Osteotomy A Radiological Study on 100 Patients. American Journal of Sports Medicine 38, 323-329, doi:10.1177/0363546509348050 (2010).	94
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67	Parvizi, J., Hanssen, A. D. & Spangehl, M. J. Total knee arthroplasty following proximal tibial osteotomy: Risk factors for failure. Journal of Bone and Joint Surgery-American Volume 86A, 474-479, doi:10.2106/00004623-200403000-00003 (2004).	91
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69	Rinonapoli, E., Mancini, G. B., Corvaglia, A. & Musiello, S. Tibial osteotomy for varus gonarthrosis. A 10- to 21-year followup study. Clinical Orthopaedics and Related Research, 185-193 (1998).	91
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72	Saragaglia, D. & Roberts, J. Navigated osteotomies around the knee in 170 patients with osteoarthritis secondary to genu varum. Orthopedics 28, S1269-S1274 (2005).	89
73	Hernigou, P. & Ma, W. Open wedge tibial osteotomy with acrylic bone cement as bone substitute. Knee 8, 103-110, doi:10.1016/s0968-0160(00)00061-2 (2001).	89
74	Gaasbeek, R. D. A., Nicolaas, L., Rijnberg, W. J., van Loon, C. J. M. & van Kampen, A. Correction accuracy and collateral laxity in open versus closed wedge high tibial osteotomy. A one-year randomised controlled study. International Orthopaedics 34, 201-207, doi:10.1007/s00264-009-0861-7 (2010).	88
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76	Naudie, D. D. R., Amendola, A. & Fowler, P. J. Opening wedge high tibial osteotomy for symptomatic hyperextension-varus thrust. American Journal of Sports Medicine 32, 60-70, doi:10.1177/0363546503258907 (2004).	88

(Continued)

Table 1

(Continued)

Rank	Article	Citations
77	Niemeyer, P. et al Two-year results of open-wedge high tibial osteotomy with fixation by medial plate fixator for medial compartment arthritis with varus malalignment of the knee. Arthroscopy-the Journal of Arthroscopic and Related Surgery 24, 796-804, doi:10.1016/j.arthro.2008.02.016 (2008).	87
78	Jackson, J. P., Waugh, W. & Green, J. P. High tibial osteotomy for osteoarthritis of the knee. The Journal of Bone and Joint Surgery. British volume 51, 88-94 (1969).	87
79	El-Azab, H., Halawa, A., Anetzberger, H., Imhoff, A. B. & Hinterwimmer, S. The effect of closed- and open-wedge high tibial osteotomy on tibial slope – A retrospective radiological review of 120 cases. Journal of Bone and Joint Surgery-British Volume 90B, 1193–1197, doi:10.1302/0301-620x.90b9.20688 (2008).	86
80	Schallberger, A., Jacobi, M., Wahl, P., Maestretti, G. & Jakob, R. P. High tibial valgus osteotomy in unicompartmental medial osteoarthritis of the knee: a retrospective follow-up study over 13-21 years. Knee Surgery Sports Traumatology Arthroscopy 19, 122-127, doi:10.1007/s00167-010-1256-4 (2011).	83
81	Salzmann, G. M. et al Sporting Activity After High Tibial Osteotomy for the Treatment of Medial Compartment Knee Osteoarthritis. American Journal of Sports Medicine 37, 312-318, doi:10.1177/0363546508325666 (2009).	83
82	Arthur, A., LaPrade, R. F. & Agel, J. Proximal tibial opening wedge osteotomy as the initial treatment for chronic posterolateral corner deficiency in the varus knee – A prospective clinical study. American Journal of Sports Medicine 35, 1844–1850, doi:10.1177/0363546507304717 (2007).	83
83	Noyes, F. R., Mayfield, W., Barber-Westin, S. D., Albright, J. C. & Heckmann, T. R. Opening wedge high tibial osteotomy – An operative technique and rehabilitation program to decrease complications and promote early union and function. American Journal of Sports Medicine 34, 1262–1273, doi:10.1177/0363546505286144 (2006).	83
84	Nagel, A., Insall, J. N. & Scuderi, G. R. Proximal tibial osteotomy. A subjective outcome study. The Journal of Bone and Joint Surgery. American volume 78, 1353–1358, doi:10.2106/00004623-199609000-00009 (1996).	82
85	Meidinger, G. et al May smokers and overweight patients be treated with a medial open-wedge HTO? Risk factors for non-union. Knee Surgery Sports Traumatology Arthroscopy 19, 333-339, doi:10.1007/s00167-010-1335-6 (2011).	78
86	Schoenecker, P. L., Meade, W. C., Pierron, R. L., Sheridan, J. J. & Capelli, A. M. Blount's disease: a retrospective review and recommendations for treatment. Journal of Pediatric Orthopedics 5, 181-186 (1985).	78
87	Asik, M. et al High tibial osteotomy with Puddu plate for the treatment of varus gonarthrosis. Knee Surgery Sports Traumatology Arthroscopy 14, 948-954, doi:10.1007/s00167-006-0074-1 (2006).	77
88	Meding, J. B., Keating, E. M., Ritter, M. A. & Faris, P. M. Total knee arthroplasty after high tibial osteotomy – A comparison study in patients who had bilateral total knee replacement. Journal of Bone and Joint Surgery-American Volume 82A, 1252–1259, doi:10.2106/00004623-200009000-00005 (2000).	77
89	Jackson, M., Sarangi, P. P. & Newman, J. H. Revision total knee arthroplasty. Comparison of outcome following primary proximal tibial osteotomy or unicompartmental arthroplasty. The Journal of Arthroplasty 9, 539-542, doi:10.1016/0883-5403(94)90102-3 (1994).	77
90	Haddad, F. S. & Bentley, G. Total knee arthroplasty after high tibial osteotomy – A medium-term review. Journal of Arthroplasty 15, 597-603, doi:10.1054/arth.2000.6621 (2000).	76
91	Borjesson, M., Weidenhielm, L., Mattsson, E. & Olsson, E. Gait and clinical measurements in patients with knee osteoarthritis after surgery: a prospective 5-year follow-up study. Knee 12, 121-127, doi:10.1016/j.knee.2004.04.002 (2005).	74
92	Marti, R. K., Verhagen, R. A. W., Kerkhoffs, G. & Moojen, T. M. Proximal tibial varus osteotomy – Indications, technique, and five to twenty-one-year results. Journal of Bone and Joint Surgery-American Volume 83A, 164-170, doi:10.2106/00004623-200102000-00002 (2001).	74
93	Mont, M. A., Antonaides, S., Krackow, K. A. & Hungerford, D. S. Total knee arthroplasty after failed high tibial osteotomy. A comparison with a matched group. Clinical Orthopaedics and Related Research, 125-130 (1994).	74
94	Aglietti, P., Rinonapoli, E., Stringa, G. & Taviani, A. Tibial osteotomy for the varus osteoarthritic knee. Clinical Orthopaedics and Related Research, 239-251 (1983).	74
95	Michaela, G., Florian, P., Michael, L. & Christian, B. Long-term outcome after high tibial osteotomy. Archives of Orthopaedic and Trauma Surgery 128, 111-115, doi:10.1007/s00402-007-0438-0 (2008).	73
96	Kim, S. E., Pozzi, A., Banks, S. A., Conrad, B. P. & Lewis, D. D. Effect of Tibial Plateau Leveling Osteotomy on Femorotibial Contact Mechanics and Stifle Kinematics. Veterinary Surgery 38, 23-32, doi:10.1111/j.1532-950X.2008.00470.x (2009).	71
97	Koshino, T. et al High tibial osteotomy with fixation by a blade plate for medial compartment osteoarthritis of the knee. The Orthopedic Clinics of North America 20, 227-243 (1989).	71
98	Kaper, B. P., Bourne, R. B., Rorabeck, C. H. & MacDonald, S. J. Patellar infera after high tibial osteotomy. Journal of Arthroplasty 16, 168-173, doi:10.1054/arth.2001.20538 (2001).	70
99	Hagstedt, B., Norman, O., Olsson, T. H. & Tjornstrand, B. Technical accuracy in high tibial osteotomy for gonarthrosis. Acta Orthopaedica Scandinavica 51, 963-970, doi:10.3109/17453678008990901 (1980).	66
100	Odenbring, S., Egund, N., Lindstrand, A., Lohmander, L. S. & Willen, H. Cartilage regeneration after proximal tibial osteotomy for medial gonarthrosis. An arthroscopic, roentgenographic, and histologic study. Clinical Orthopaedics and Related Research, 210-216 (1992).	65

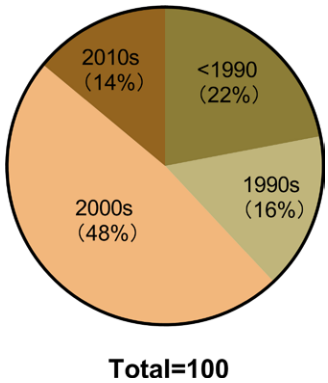

Figure 2. Time distribution of 100 top-cited articles related to high tibial osteotomy. A majority of articles were published in the 2000s (n = 48).

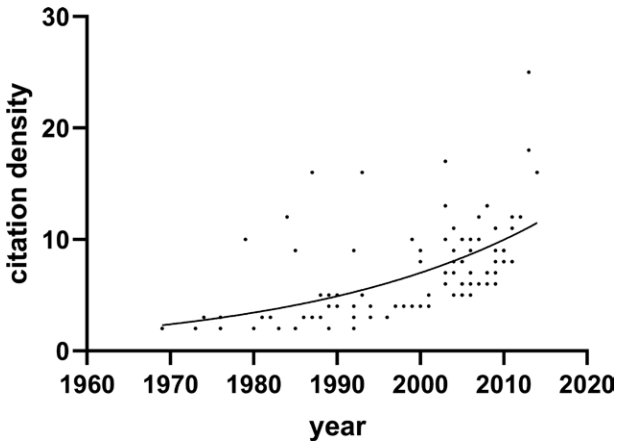

Figure 3. Time-dependent citation density trend. Mann–Kendall trend test showed an increasing trend between the citation density and the time (*P* = 1.342E-10).

18% was for biomechanical, histological, and other studies. Using the Kruskal–Wallis test, there was a significant difference observed between the distinguished themes and citations per article (*P* = .009) (Fig. 6B).

3.3. Keywords

Published articles were divided into two periods: Before 2005 (n = 67) and from 2005 onwards (n = 33). The network analysis results of the key words in these two periods show that "long-term follow-up, open wedge osteotomy, OA" are highly concentrated in the earlier period, while "TomoFix plate" is highly concentrated in the later period (Fig. 7).

Keywords of literatures published in the last 5 years were clustered into three clusters. Cluster 1 on the top (blue) included different fixing materials and cluster 2 in the middle (green) included multiple surgical approaches and cluster 3 in the lower (red) included keywords related to clinical study (Figure S1, Supplementary Digital Content 2, http://links.lww.com/MD/H166).

3.4. Evidence level

Nearly half (n = 48) of the 100 articles were level IV evidence with a mean TNC of 141 (SD = 97). There was an even contribution among the other evidence levels: Level II (n = 17), level V (n = 14), level III (n = 12), and level I (n = 9) with TNC's of 126 (SD = 58), 156 (SD = 91), 121 (SD = 78), and 113 (SD = 32), respectively. Kruskal–Wallis test showed no significant relation between TNC and level of evidence (*P* = .26), also between the level of evidence and ACY (*P* = .43) (Fig. 8). The correlation test showed no significant relationship between the level of evidence and year of publication (*P* = .08). These might be confounding factors.

3.5. The 10 most-cited articles during the last 5 years

The list of the top 10 HTO articles during the last 5 years is shown in Table 2. The number of citations ranged from 24 to 71.

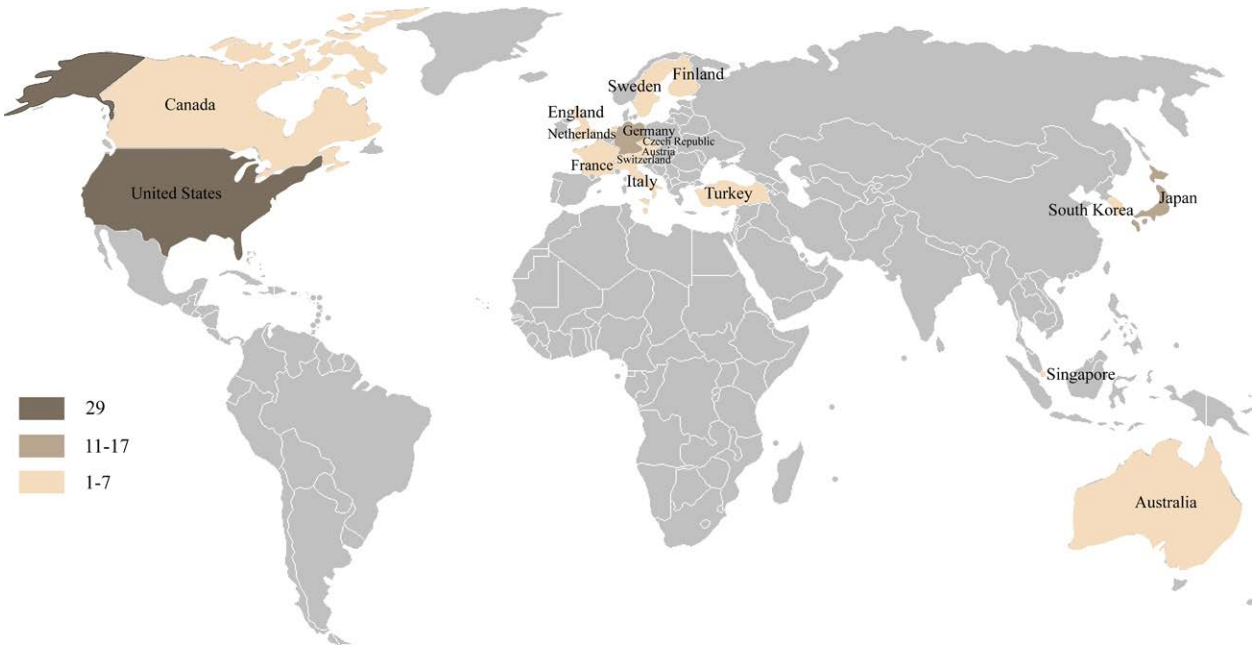

Figure 4. Geographical distribution of the top 100 articles. The map showed that 46 of the top 100 articles came from the USA and Germany.

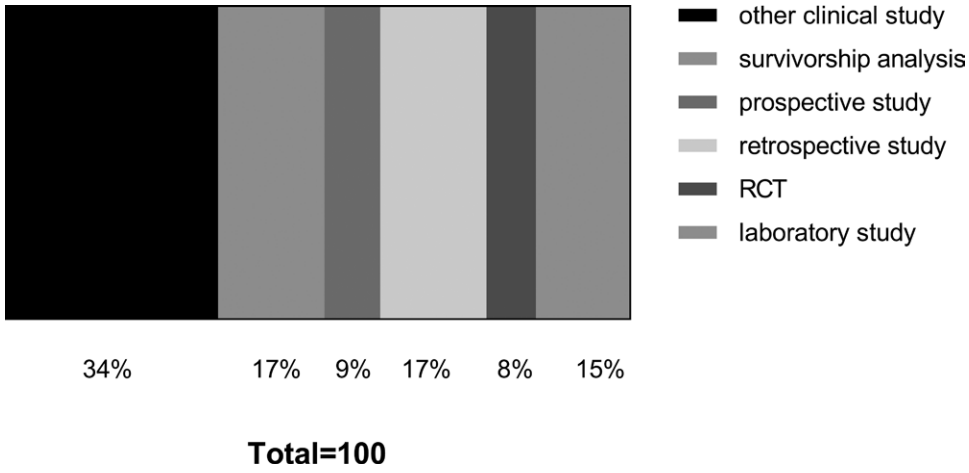

Figure 5. The type distribution of the top 100 most cited articles.

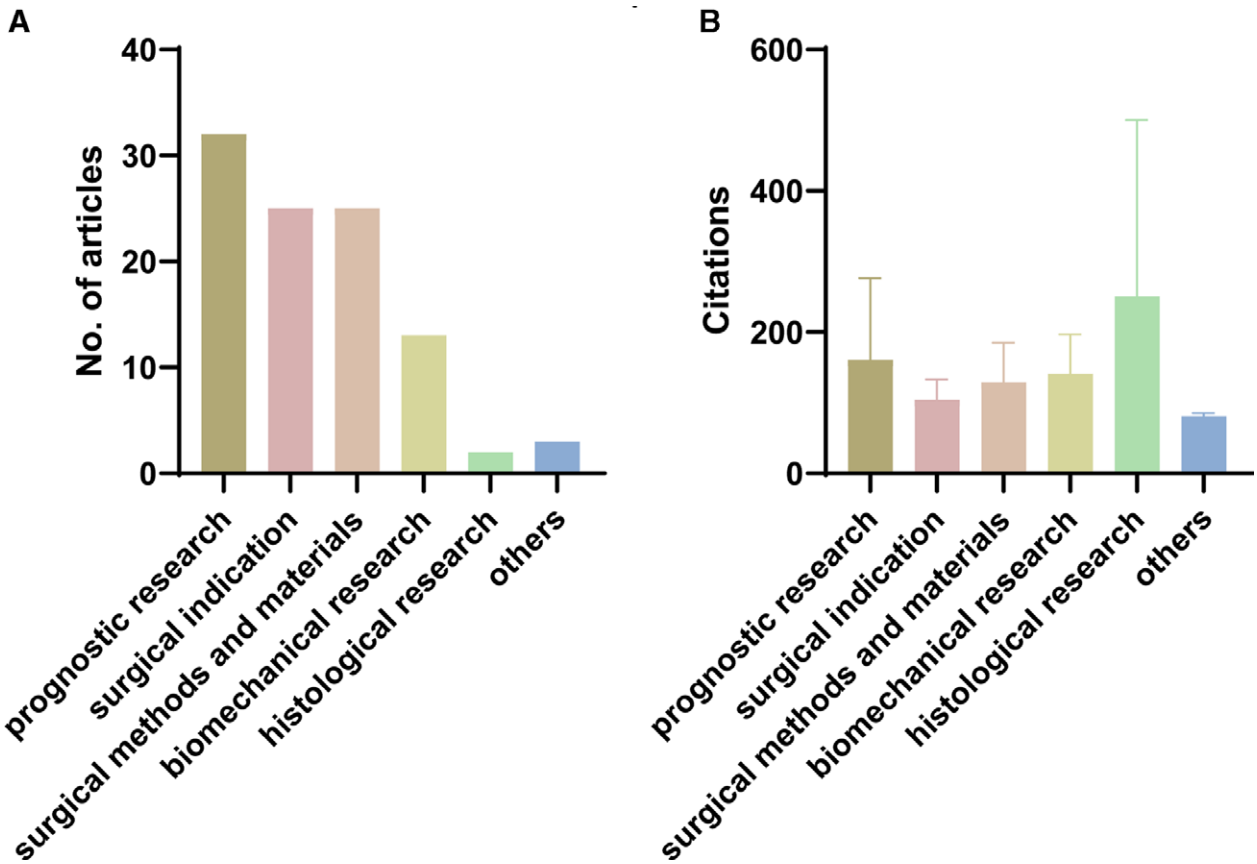

Figure 6. The themes distribution of all the articles. (A) The number of articles for each identified theme. (B) Mean citation per article based on theme. Kruskal–Wallis test revealed a significant difference in citations per article among the various themes (P = .009).

4. Discussion

This analysis aimed at providing an elaborate evaluation of the top 100 most cited articles on HTO based on the Web of Science Core Collection. Currently, there is no bibliometric analysis available relating to HTO. In our analyses, several trends and patterns were identified.

We found that more than half (n = 62) of the TNCs were published between 2000–2014, which was not consistent with previous studies. A former bibliometric analysis on orthopedics in general in 2011 concluded that the peak period for TNCs was from 1965 to 1980.[19] This difference could reflect changing trends in topical interests and increasing online accessibility of new articles through the internet. The improvement in total joint replacement outcomes in the mid-1990s decreased the reliance on HTO, reflecting a low number of papers published in this period among the top 100 list. The short-term success of TKA led to an overuse of total joint replacements worldwide in the last decade.[20] Nowadays, awareness has increased that there is room for improvement in the outcome after TKA due to the relatively high risk of surgery-related complications, such as residual pain, stiffness, and instability.[21] Simultaneously, the advent of locking plates

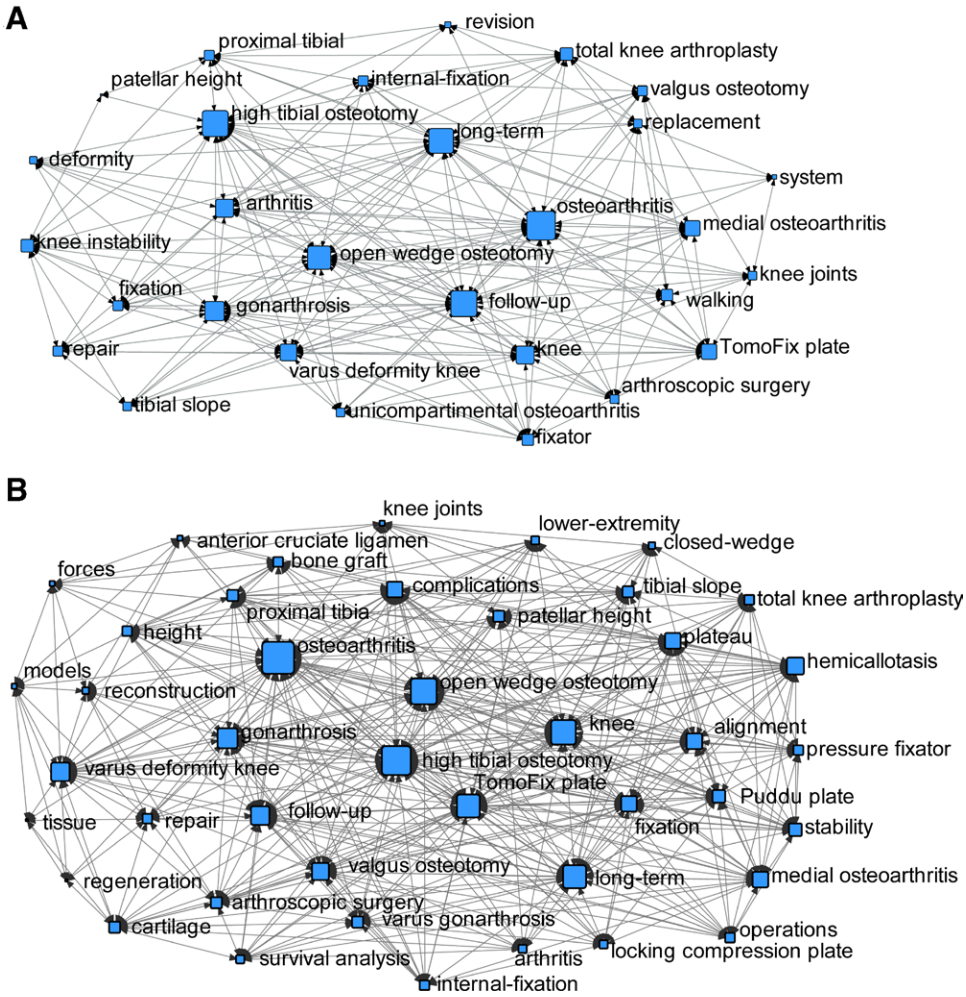

Figure 7. The degree centrality analysis for articles published before 2005 (A) and after 2005 (B). Long-term, follow-up, open wedge osteotomy, and osteoarthritis had a high degree of centrality before 2005 (67 articles); while open wedge osteotomy, osteoarthritis, and TomoFix plate had a high degree of centrality after 2005 (33 articles).

has revived the practice of peri-knee osteotomy during the last 10 years. The shift back toward joint preserving surgery has been supported by reports showing a dramatically decreased risk of implant failure and other complications since the introduction of the TomoFox plate system.[22] Although the role of high tibia osteotomy in knee surgery has not yet to be determined, the rapid evolution in the field of knee osteotomy will undoubtedly maintain the status of HTO as a highly valuable and well-respected surgical treatment option for the painful malaligned knee.[23,24]

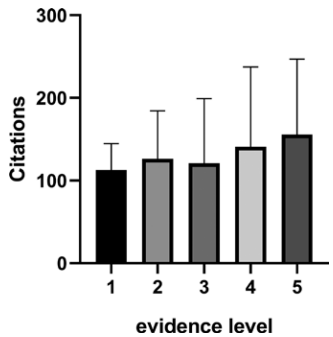

Figure 8. Mean citation per article based on level of evidence. No significant difference in citations per article among the various levels of evidence has been found by using the Kruskal–Wallis test ($P = .26$).

Approximately half (n = 56) of the top 100 articles were published in high impact factor orthopedics journals (IF2019 > 4.0), such as the Journal of Bone and Joint Surgery-American Volume, American Journal of Sports Medicine, and Arthroscopy-the Journal of Arthroscopic and Related Surgery. This phenomenon indicated that journals with high IFs attracted more authors prioritizing these journals to publish high-quality studies.[25]

Overall, 46 of the top 100 articles came from the USA and Germany. Firstly, the USA occupies an indispensable position within the vast field of clinical medicine, such as radiological subspecialties,[26] cardiology,[27] general surgery,[26] and urology.[28] This is linked to a large scientific community with abundant financial resources. Secondly, KOA was highly prevalent in Germany, especially in the elderly population.[29] Moreover, the German government provides large and pluralistic medical and research funding, high academic quality, and a favorable academic infrastructure. These conditions benefit research in multi-disciplinary fields, including orthopedics. It is in this environment that the book "Kniegelenknahe Osteotomien" (Osteotomies around the Knee) appeared, focusing on the introduction and development of the TomoFix plate system and first published in the German language.

In the 100-top list, the evaluation of postoperative outcomes as well as breakthroughs in surgical techniques count the two

Table 2

List of the 10 top-cited articles in high tibial osteotomy during the last 5 years.

Rank	Title	PMID	Citations
1	Ten-Year Results of Medial Open-Wedge High Tibial Osteotomy and Chondral Resurfacing in Severe Medial Osteoarthritis and Varus Malalignment	29589953	71
2	Effect of Increased Coronal Inclination of the Tibial Plateau After Opening-Wedge High Tibial Osteotomy	29685834	38
3	Development of the double level osteotomy in severe varus osteoarthritis showed good outcome by preventing oblique joint line.	30413943	37
4	Diagnostic Value of Computed Tomography and Risk Factors for Lateral Hinge Fracture in the Open Wedge High Tibial Osteotomy	29229417	28
5	Mechanism and influencing factors of proximal fibular osteotomy for treatment of medial compartment knee osteoarthritis: A prospective study	29848141	27
6	Deterioration of patellofemoral cartilage status after medial open-wedge high tibial osteotomy	30196435	26
7	Comparison of Clinical and Radiologic Outcomes Between Normal and Overcorrected Medial Proximal Tibial Angle Groups After Open-Wedge High Tibial Osteotomy	31604511	25
8	Tibial Slope and Its Effect on Graft Force in Posterior Cruciate Ligament Reconstructions	30896980	25
9	Return to Sports After Tibial Tubercle Osteotomy for Patellofemoral Pain and Osteoarthritis	29229415	25
10	Are three-dimensional patient-specific cutting guides for open wedge high tibial osteotomy accurate? An in vitro study	29986731	24

fastest-growing areas of academic interest. Such trends were not surprising, considering new surgical material was one of the overall leading causes of osteotomy's development prospects.[30,31] Research on special implants for different types of osteotomy also had its place. HTO has been defined as an effective surgical option for symptomatic and malaligned KOA. Therefore, many studies have targeted more specific conditions, such as unicompartmental OA, malalignment of the leg and ligaments, instability of the knee, and complex lower limb deformities. Within this subcategory, TKA after HTO is still a controversial issue and needs further attention. Some see HTO as a final solution, others regard HTO as a temporary option to delay TKA. Some studies showed that TKA after HTO operation was technically more demanding than primary TKA. However, up till now no clear differences in the clinical scores or range of motion could have been identified between primary TKA versus TKA after HTO.[32] As the burden of OA is projected to rise, the future bibliometric analysis may identify more focus on this issue.

Papers published before 2005 showed a preference for survival analysis. This possibly suggests that the studies in the early years related to surgical complications and prognosis. The degree of centrality analysis of the author's keywords indicated that the centrality of "long-term follow-up" decreased with time. New keywords occurred such as "regeneration," "bone graft," "tissue," "alignment," indicating the publication of studies on the application of grafts and bone substitutes to fill the open wedge osteotomy gap, enhance stability and accelerate bone healing. Bone grafting in OWHTO remains controversial. The available evidence was not sufficient enough to agree with the superiority of OWHTO with bone graft to OWHTO without bone graft.[33] Nevertheless, other studies support autograft bone augmentation for reasons of faster union and better clinical outcomes.[34] The appearance of the keyword "alignment" indicates the development of computer-assisted techniques and navigation in order to optimize the postoperative alignment of the mechanical weight-bearing axis.[35] In keywords of literatures published in the last 5 years, autologous implant and cartilage repair have come to occupy an important place. Besides, the list of the 10 most cited tibial osteotomy articles in the past 5 years reflects the chondral resurfacing procedure can be regarded as the hotspot. Also, these two different approaches to the analysis of the last 5 years of literature suggest improvement and evaluation of surgical methods are always important. OWHTO gradually occupies a more important position.

Articles with high overall citations but low ACY were more likely to be from the historical record. Most of the top 10 articles ranked by ACY were published in the 21st century (Table S2, Supplementary Digital Content 3, http://links.lww.com/MD/H167). ACY is regarded as an indicator of future research. The article with the highest ACY focused on OWHTO with the TomoFix plate, which was published by Wong, Kin 2013.[36] The research topics of top ACY papers and the 10 TNCs in HTO during the past 5 years shared the same topics. Over half of the top 10 articles ranked by ACY focused on the optimization of OWHTO in the area of mesenchymal stem cells and fixation devices. Prognostic research on OWHTO remains a topic of interest as well. These trends could guide current investigators.

Besides, the choice for a winner between the two types of osteotomy can be viewed from multiple angles. Accordingly, there are endless studies on the comparison of closed wedge high tibial osteotomy (CWHTO) and OWHTO. CWHTO is a historic method, which has certain advantages in the degree of correction and initial stability. The disadvantages of CWHTO are postoperative anatomical changes (there are more surgical technical concerns in TKA conversion from CWHTO than from OWHTO),[37] fibular complications,[38] and higher surgical skill requirements. Although some studies have shown that the clinical results of OWHTO and CWHTO for varus deformity are similar,[39,40] recent researches have concluded that OWHTO has several advantages over CWHTO, including shorter operating time, shorter recovery time,[41] the higher survival rate at 10 years,[42] and a wider range of motion.[43] OWHTO has gradually replaced CWHTO, whereas some indications remain for the closed wedge technique: patella Baja and planning a lateral arthrotomy.[44]

The level of evidence analysis demonstrated that the majority of studies performed as level IV, comparable to research on orthopedic knee surgery in general and, for instance, bariatric surgery.[45] The numbers occupied by other levels were relatively close. This may be because earlier research used uncontrolled case series observations as the main method to answer prognostic questions. The future research direction seems to aim at surgical technology and the research of new materials. Consequently, the share of randomized controlled trials may increase.

Despite answering several questions, this study has several limitations. Firstly, there is a time difference between publications. Over time, the count of citations in earlier published articles has an advantage over more recent publications. Without a doubt, new results not only corroborate previous research of HTO but also introduce new developments. Secondly, language restrictions exist. This bibliometric analysis only used English-language articles, primarily because the Web of Science database was limited by its heavy bias toward English journals.[46]

5. Conclusion

This article analyses the top 100 most cited articles in HTO and highlights the theme and prospect of HTO research. Most of the top-cited papers are published in high IF journals, mainly from the United States and Germany, followed by Japan. Postoperative research using survival analysis occupies an important position. Research on the chondral resurfacing procedure, improvements of OWHTO gradually increased in past 5 years. Such analyses may provide suggestions for researchers and funding agencies. Future research may focus on surgical technology, cartilage repair, and new fixation devices.

Author contributions

CW and WX conceptualized this review, decided on the content, and wrote the manuscript. WZ, NT, YS, and BJ prepared the figures. LHW and HX prepared the tables. YL and TH revised this review. All authors reviewed the manuscript.
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Data curation: Cong Wei, Wenqing Xie, Yang Su, Haijun Xu.
Formal analysis: Yang Su, Buchan Jiang.
Methodology: Wenchao Zhang.
Software: Wenchao Zhang, Ning Tang, Yang Su, Lucas H. Walschot.
Supervision: Lucas H. Walschot.
Validation: Wenchao Zhang, Buchan Jiang.
Visualization: Ning Tang, Haijun Xu.
Writing – original draft: Cong Wei, Wenqing Xie.
Writing – review & editing: Yusheng Li, Tianlong Huang.

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