A Bibliometric Analysis of the Field of Computer-Assisted Orthopedic Surgery during 2002–2021

Chae-Chil Lee, MD, Kwang-Hwan Jung, MD, Kyung-Joo Lee, MD, Ki-Bong Park, MD

Department of Orthopedic Surgery, Ulsan University Hospital, University of Ulsan College of Medicine, Ulsan, Korea

Background: This study aimed to investigate the characteristics of research articles and research trends in computer-assisted orthopedic surgery (CAOS) by conducting bibliometric analyses.

Methods: CAOS-related research articles published in international journals from 2002 to 2021 were collected using the PubMed database and analyzed using the bibliometric method. Their publication year, journal name, corresponding author's country name, and the number of citations of all collected articles were noted. Contents of the articles were analyzed to evaluate the time point and anatomical site at which the digital technique was applied. Further, the 20-year period was divided into two halves of 10 years each to analyze the research trends.

Results: A total of 639 CAOS-related articles were identified. An average of 32.0 CAOS-related articles were published annually, with an average of 20.6 and 43.3 published in the first half and second half, respectively. Of all articles, 47.6% were published in the top 10 journals, and 81.2% were written in the top 10 countries. The total numbers of citations were 11.7 and 6.3 in the first and second halves, respectively, but the average annual number of citations was higher in the second half than in the first one. Articles on application of digital techniques during surgery were 62.3% and those on pre-surgery application were 36.9%. Further, articles in the knee (39.0%), spine (28.5%), and hip and pelvis (21.5%) fields accounted for 89.0% of the total publications. But the increase in publications in the said period was highest in the fields of the hand and wrist (+1,300.0%), ankle (+466.7%), and shoulder (+366.7%).

Conclusions: Over the last 20 years, the publication of CAOS-related research articles in international journals has grown steadily. Although the knee, spine, hip, and pelvis fields account for most CAOS-related research, research in new fields is also increasing. This study analyzed the types of articles and trends in CAOS-related research and provided useful information for future research in the field of CAOS.

Keywords: *Bibliometrics, Computer-assisted surgery, Orthopedics, Research*

Computer-assisted orthopedic surgery (CAOS) is one of the most important and interesting fields in clinical or-thopedics, as it enables precise treatment of musculoskel-etal diseases by employing advanced navigation systems and surgical tools.[1] Previously, CAOS was introduced as surgery using robotic or image-guided technologies in various orthopedic fields, but recently, new categories of CAOS have been created by applying digital techniques to clinical orthopedics.[1] Digital anatomical models, design of virtual surgery, three-dimensional (3D) printing, navi-gation or robotic surgery, and finite element analysis are being actively studied within the scope of CAOS, and the

228

Lee et al. Bibliometric Analysis of Computer-Assisted Orthopedic Surgery
Clinics in Orthopedic Surgery • Vol. 15, No. 2, 2023 • www.ecios.org

overall scope of CAOS is expected to expand further in the future.[2-4] CAOS has also been traditionally applied in arthroplasty and spinal surgery.[5] Currently, applications are being tried in trauma fields, such as pelvic fractures[6,7] and ailments of upper extremities[8,9] and feet.[10,11]

Bibliometric studies are a branch of library science that uses mathematical and statistical methods to analyze articles, books, and other documents[12] to evaluate the performance of each article or provide a comprehensive evaluation of research trends.[13,14] Therefore, bibliometric analyses help readers to understand the contents and trends in research in a specific field. Bibliometric analyses have been performed in orthopedics and analyses of the nature of publications have been reported,[15,16] but there has been no bibliometric study focusing on articles related to CAOS. Presuming that CAOS-related research may have changed over time in terms of the number of published articles and citations and the content of research fields, this study aimed to investigate the characteristics of research articles and research trends in CAOS by conducting bibliometric analyses.

METHODS

Institutional Review Board approval was waived because this study did not involve human subjects. No informed consent was necessary for the study.

Search Strategy
A survey of PubMed online database was conducted using two MeSH terms, "surgery, computer-assisted" and "orthopedic" as keywords. The details of the literature survey were as follows: (1) articles written in English, (2) articles published in international journals, and (3) articles published between January 1, 2002, and December 31, 2021. The title and abstract of each article were noted and articles that were not related to CAOS were excluded. In cases of ambiguity in this process, full-text of the articles was evaluated. We also excluded specific types of articles such as meta-analyses, systematic reviews, editorials, comments, and guidelines. Two orthopedic surgeons conducted (CCL and KBP) the selection and analyzed the contents of the articles to reach a consensus; another orthopedic surgeon (KHJ) was included when opinions were not in agreement.

Bibliometric Analyses
For bibliometric information of the research articles, publication year, journal name, and the corresponding author's country name for each article were noted. The average number of articles published each year was confirmed by checking the publication year of the articles. Top ten journals were listed and the proportion of articles published in them among all published articles during the analysis period was noted. Further, the proportion of articles published in top ten countries was also noted.

At the time of data collection (December 2021), the "cited by" section of "page navigation" was checked for each article in PubMed and the total number of citations was noted. For articles with high citations, the average number of citations per year after publication was calculated to compensate for articles published in the beginning of the analysis period. For example, if an article published in 2014 was cited 12 times as of December 2021, the average number of citations per year for this article was considered 1.5 (total number of citations per year from publication to data collection, which was 12/8).

Content Analysis
A comprehensive review was performed for the components of CAOS system: classified design of rapid prototype, 3D reconstruction, and virtual operation as preoperative content; navigation procedures and robotic-assisted surgery as intraoperative content; and finite element analysis and comparative analysis with preoperative data as postoperative content.[1,2] The content of the articles was categorized as preoperative, intraoperative, and postoperative according to when a digital technique was applied in the management process. The research fields of CAOS were classified on the basis of anatomical sites into spine, shoulder, elbow, wrist and hand, hip and pelvis, knee, foot, and ankle.

Analysis Strategy for Research Trends
To analyze the research trend, the 20-year period was divided into two halves of 10 years each: the first half (2002–2011) and the second half (2012–2021). The average annual number of published articles, the total number of citations, and the average annual number of citations were checked, and the increase or decrease in a specific research field for an anatomical site was compared between the first and second halves.

Statistical Analyses
We performed an independent t-test to compare the values between the two periods (first half vs. second half) and used the IBM SPSS ver. 20.0 (IBM Corp., Armonk, NY, USA) for all analyses. The threshold for statistical significance was set at $p < 0.05$.

229

Lee et al. Bibliometric Analysis of Computer-Assisted Orthopedic Surgery
Clinics in Orthopedic Surgery • Vol. 15, No. 2, 2023 • www.ecios.org

RESULTS

A total of 1,084 articles were initially collected, in which 827 research articles were related to CAOS. Of these, 188 publications were excluded as they were meta-analyses, systematic reviews, editorials, and guidelines. The final dataset comprised 639 articles (Fig. 1).

Bibliometric Analyses

Number of published articles

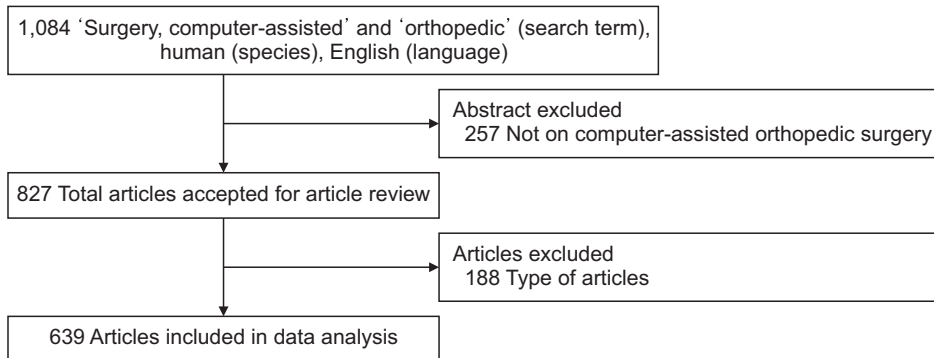Fig. 2 shows the cumulative and yearly distribution of articles related to CAOS over the last 20 years. An aver-

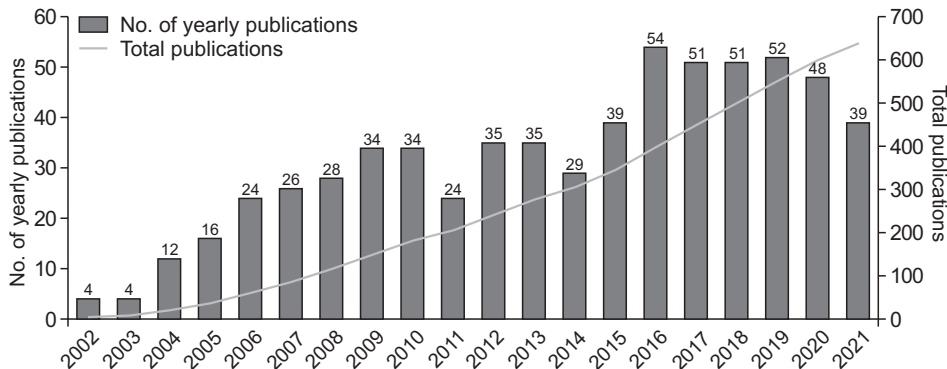**Fig. 1.** Flowchart of selected articles.

Fig. 2. Cumulative number and yearly distribution of computer-assisted orthopedic surgery-related research articles published in international journals over the study period in each year.

Table 1. List of the Top 10 Journals and the Number of Published Articles in Each Journal

Rank	Journal name	No. of published articles
1	*Orthopedics*	43
2	*Knee Surgery Sports Traumatology Arthroscopy*	42
3	*Journal of Arthroplasty*	39
4	*Computer Aided Surgery*	31
	International Journal of Computer Assisted Radiology and Surgery	30
5	*International Journal of Medical Robotics and Computer Assisted Surgery*	30
7	*Clinical Orthopaedics and Related Research*	25
8	*European Spine Journal*	23
9	*Knee*	22
10	*Spine (Phila Pa 1976)*	19
Total		304 (47.6%*)

*Total: 639 articles published in 119 journals.

230

Lee et al. Bibliometric Analysis of Computer-Assisted Orthopedic Surgery
Clinics in Orthopedic Surgery • Vol. 15, No. 2, 2023 • www.ecios.org

age of 32.0 CAOS-related articles were published per year during the 20-year period. The average number of articles published per year increased except in these 5 years: 2011, 2014, 2017, 2020, and 2021. An average of 20.6 and 43.3 articles were published in the first and second halves, respectively, indicating a significant increase ($p < 0.01$).

Top 10 journals
Of the 639 articles published in 119 journals, 304 (47.6%) were published in the top 10 journals. Table 1 shows the names of the top 10 journals and the number of articles published in each. The top three journals were *Orthopedics*, *Knee Surgery Sports Traumatology Arthroscopy*, and *Journal of Arthroplasty*.

Top 10 countries
Of the 639 articles published in 34 countries, 519 of all articles (81.2%) were written in the top 10 countries. The articles written in the top 1 and 2 countries accounted for 31.8% of the total articles. The top 1–3 countries were the United States of America, Germany, and Japan (Fig. 3).

Total and average annual number of citations
The total number of citations of 639 articles was 5,141,

with an average of 8.1 citations. The total number of citations was high in the first half (11.7) than the second half (6.3), but the average annual number of citations was high in recently published articles (Fig. 4).

Content Analysis
Period of application of digital techniques
Research on digital techniques applied before, during, and after the orthopedic surgery accounted for 36.9%, 62.3%, and 0.8% of all articles, respectively. Table 2 shows the frequently used keywords in the classification based on the application time of digital techniques in the surgical procedure.
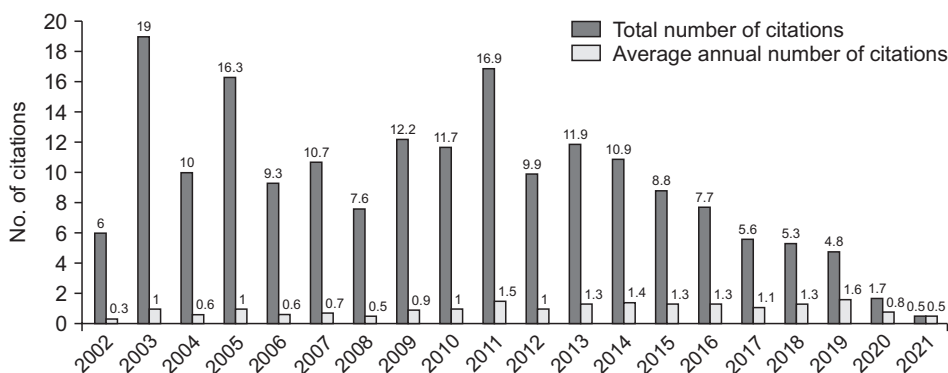
Application of CAOS based on the anatomical site
In this analysis, articles on general topics (n = 105), such as tumors, training, and education, were excluded. Altogether, 534 articles describing the specific anatomical sites on which CAOS was applied were included. A total of 208 articles (39.0%) were on the knee, 152 (28.5%) on the spine, and 115 (21.5%) on the hip and pelvis. Most research subjects were in the fields of the knee, spine, hip, and pelvis.
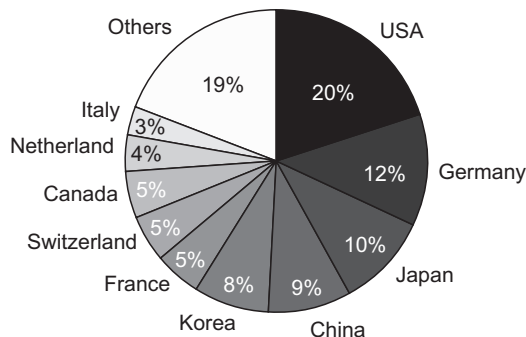
Fig. 3. Pie chart demonstrating the percentage of countries of the corresponding author of each article.

Table 2. Frequency of Use of Keywords According to the Period of Application of Digital Technique				
Period of application of digital technique	Keywords	Total	First half	Second half
Preoperative	Design of rapid prototype	13	4	9
	Three-dimensional reconstruction	52	6	46
	Virtual operation	24	1	23
Intraoperative	Navigation procedures	205	59	146
	Robotic-assisted surgery	19	5	14
Postoperative	Finite element analysis	4	2	2

Fig. 4. Total and average annual number of citations over the study period in each year.

231

Lee et al. Bibliometric Analysis of Computer-Assisted Orthopedic Surgery

Clinics in Orthopedic Surgery • Vol. 15, No. 2, 2023 • www.ecios.org

Table 3. Growth in CAOS-Related Articles Studied in Each Anatomical Site over the Last 20 Years

Anatomical site	No. of publications			Rate of change (%)	Rank in growth rate
	Total	First half	Second half		
Knee	208	90	118	31.1	6
Spine	152	39	113	189.7	4
Hip and pelvis	115	36	79	119.4	5
Foot and ankle	20	3	17	466.7	2
Shoulder	17	3	14	366.7	3
Hand and wrist	15	1	14	1,300.0	1
Elbow	7	0	7	-	-

CAOS: computer-assisted orthopedic surgery.

However, from the first half to the second half, the increase in the number of published articles was highest for the hand and wrist (+1,300.0%), followed by the foot and ankle (+466.7%) and the shoulder (+366.7%) (Table 3).

DISCUSSION

The most important findings of the present study were that the numbers of CAOS-related research articles published in international journals and their citations showed a gradual increase over the last 20 years. The fields of knee, spine, hip, and pelvis accounted for most CAOS-related research, but research in new fields such as hand and wrist, foot and ankle, and shoulder were increasing.

Regarding the total number of citations, it was assumed that the articles published in the first half had a higher number of citations due to the longer period of time they were available to researchers after publication. Regarding the average annual number of citations after publication, it was assumed that the significant increase in the second half was due to the better quality of research and correlation between the studies.

On the type of digital techniques used, most research (62.3%) was conducted in the field of navigation- and robot-assisted surgery, that is, intraoperative digital techniques. Recently, research in the fields of augmented, virtual, and mixed reality is being actively conducted; the authors, therefore, believe that studies on preoperative digital techniques would gradually increase. Studies on postoperative digital techniques were few because this study included only finite analyses for this category.

During the search for CAOS-related research, all CAOS studies published in the late 1990s were found to be conducted in the field of arthroplasty and spine.[17-21] Studies on the knee, hip, and spine were judged to be in the top rank in the classification based on anatomical site since research in arthroplasty and spine has been actively conducted since the early days of CAOS-related research.

The research trend in published articles confirmed a clear increase in publications related to upper extremities, foot, and ankle compared to the knee joint, hip and pelvis, and spine fields, which accounted for most CAOS-related studies over the last 20 years. We interpreted this as a relative increase in the latter half because the total number of published articles during the first half was comparatively smaller. With the gradual increase in the CAOS application, research in various fields using this modality will increase in the future.

The limitations of this study include the use of a single database for search, search using specific terms, and no content analysis for new research fields. This study used only two search terms for data extraction. However, because the two search terms—"surgery, computer-assisted" and "orthopedic"—are MeSH terms, the authors thought that these would be suitable for searching CAOS-related articles. Another limitation is that the classification of previous studies[1,2] used for content analysis in this study did not include new fields that have recently been in the spotlight. CAOS emerged as a new and independent area approximately two decades ago. It stands for approaches that use computer-enabled tracking systems or robotic devices to improve visibility of the surgical field, thereby increasing accuracy and outcome improvement in a variety of surgical procedures.[22] However, it has recently been recognized that new fields, such as digital orthopedic anatomy, biomechanical research, virtual operation train-

232

Lee et al. Bibliometric Analysis of Computer-Assisted Orthopedic Surgery
Clinics in Orthopedic Surgery • Vol. 15, No. 2, 2023 • www.ecios.org

ing, education procedures, artificial intelligence (AI), and deep learning are also included in the CAOS category.[23-25] There is a consensus that new fields such as AI and deep learning should also be included in CAOS classification; studies on content analysis in these fields should be conducted in the future.

Finally, the authors do believe that it would be a strength of this study to have collected all CAOS-related articles published in various journals over the last 20 years and present the results of bibliometric analyses and the characteristics and trends of the related research. Over the last 20 years, the publication of CAOS-related research articles in international journals has grown steadily. Although the knee, spine, hip, and pelvis fields account for most CAOS-related research, research in new fields is also increasing. This study analyzed the types of articles and trends in CAOS-related research and provided useful information for future research in the field of CAOS.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Chae-Chil Lee   https://orcid.org/0000-0001-7323-0761
Kwang-Hwan Jung https://orcid.org/0000-0002-6222-3803
Kyung-Joo Lee   https://orcid.org/0000-0002-4005-1772
Ki-Bong Park   https://orcid.org/0000-0002-2978-8300

REFERENCES

1. Kubicek J, Tomanec F, Cerny M, Vilimek D, Kalova M, Oczka D. Recent trends, technical concepts and components of computer-assisted orthopedic surgery systems: a comprehensive review. Sensors (Basel). 2019;19(23):5199.

2. Pei GX, Yan YB. Current status and progress of digital orthopaedics in China. J Orthop Transl. 2014;2(3):107-17.

3. Karhade AV, Schwab JH, Bedair HS. Development of machine learning algorithms for prediction of sustained postoperative opioid prescriptions after total hip arthroplasty. J Arthroplasty. 2019;34(10):2272-7.

4. Pearle AD, Kendoff D, Musahl V. Perspectives on computer-assisted orthopaedic surgery: movement toward quantitative orthopaedic surgery. J Bone Joint Surg Am. 2009;91 Suppl 1: 7-12.

5. Kowal J, Langlotz F, Nolte LP. Basics of computer-assisted orthopaedic surgery. In: Stiehl JB, Konermann WH, Haaker RG, DiGioia AM, eds. Navigation and MIS in orthopedic surgery. Berlin, Heidelberg: Springer; 2007. 2-8.

6. Zeng C, Xing W, Wu Z, Huang H, Huang W. A combination of three-dimensional printing and computer-assisted virtual surgical procedure for preoperative planning of acetabular fracture reduction. Injury. 2016;47(10):2223-7.

7. Hung CC, Li YT, Chou YC, et al. Conventional plate fixation method versus pre-operative virtual simulation and three-dimensional printing-assisted contoured plate fixation method in the treatment of anterior pelvic ring fracture. Int Orthop. 2019;43:425-31.

8. Vlachopoulos L, Schweizer A, Meyer DC, Gerber C, Furnstahl P. Three-dimensional corrective osteotomies of complex malunited humeral fractures using patient-specific guides. J Shoulder Elbow Surg. 2016;25(12):2040-7.

9. Chen Y, Jia X, Qiang M, Zhang K, Chen S. Computer-assisted virtual surgical technology versus three-dimensional printing technology in preoperative planning for displaced three and four-part fractures of the proximal end of the humerus. J Bone Joint Surg Am. 2018;100(22):1960-8.

10. Weigelt L, Furnstahl P, Hirsiger S, Vlachopoulos L, Espinosa N, Wirth SH. Three-dimensional correction of complex ankle deformities with computer-assisted planning and patient-specific surgical guides. J Foot Ankle Surg. 2017;56(6): 1158-64.

11. Qiang M, Zhang K, Chen Y, et al. Computer-assisted virtual surgical technology in pre-operative design for the reconstruction of calcaneal fracture malunion. Int Orthop. 2019; 43(7):1669-77.

12. Similowski T, Derenne JP. Bibliometry of biomedical periodicals. Rev Mal Respir. 1995;12(6):543-50.

13. Grossi F, Belvedere O, Rosso R. Geography of clinical cancer research publications from 1995 to 1999. Eur J Cancer. 2003; 39(1):106-11.

14. Thomas BJ, Ouellette H, Halpern EF, Rosenthal DI. Automated computer-assisted categorization of radiology reports. AJR Am J Roentgenol. 2005;184(2):687-90.

15. Park SH, Jung KH, Chang SW, Jang SM, Park KB. Trends in knee surgery research in the official journal of the Korean Knee Society during the period 1999-2018: a bibliometric review. Knee Surg Relat Res. 2020;32(1):28.

16. Eom SH, Bamne AB, Chowdhry M, Chae IS, Kim TK. Bibliometric analysis of orthopedic literature on total knee arthroplasty in Asian countries: a 10-year analysis. Knee Surg

233

Lee et al. Bibliometric Analysis of Computer-Assisted Orthopedic Surgery

Clinics in Orthopedic Surgery • Vol. 15, No. 2, 2023 • www.ecios.org

Relat Res. 2015;27(3):149-55.

17. Matsen FA 3rd, Garbini JL, Sidles JA, Pratt B, Baumgarten D, Kaiura R. Robotic assistance in orthopaedic surgery: a proof of principle using distal femoral arthroplasty. Clin Orthop Relat Res. 1993;(296):178-86.

18. La Palombara PF, Fadda M, Martelli S, Marcacci M. Minimally invasive 3D data registration in computer and robot assisted total knee arthroplasty. Med Biol Eng Comput. 1997;35(6):600-10.

19. Niethard FU. Computer-assisted orthopedic surgery (CAOS) in hip joint prosthetics. Z Orthop Ihre Grenzgeb. 1999;137(2):99-100.

20. Amiot LP, Labelle H, DeGuise JA, Sati M, Brodeur P, Rivard CH. Computer-assisted pedicle screw fixation: a feasibility study. Spine (Phila Pa 1976). 1995;20(10):1208-12.

21. Nolte LP, Zamorano LJ, Jiang Z, Wang Q, Langlotz F, Berlemann U. Image-guided insertion of transpedicular screws: a laboratory set-up. Spine (Phila Pa 1976). 1995;20(4):497-500.

22. Zheng G, Nolte LP. Computer-assisted orthopedic surgery: current state and future perspective. Front Surg. 2015;2:66.

23. Reina N. Connected orthopedics and trauma surgery: new perspectives. Orthop Traumatol Surg Res. 2019;105(1S):S15-22.

24. Kalmet PH, Sanduleanu S, Primakov S, et al. Deep learning in fracture detection: a narrative review. Acta Orthop. 2020; 91(2):215-20.

25. Xue D, Xu HL, Wang W. Progress on artificial intelligence assisted X-ray film recognition in orthopedics. Zhongguo Gu Shang. 2020;33(9):887-90.