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Original Research

A Bibliometric Analysis of the Top 100 Most Influential Studies on Robotic Arthroplasty

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A R T I C L E I N F O

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A B S T R A C T

Background: The use of robotics in arthroplasty surgery has increased substantially in recent years. The purpose of this study was to objectively identify the 100 most influential studies in the robotic arthroplasty literature and to conduct a bibliometric analysis of these studies to describe their key characteristics.
Methods: The Clarivate Analytics Web of Knowledge database was used to gather data and metrics for robotic arthroplasty research using Boolean queries. The search list was sorted in descending order by the number of citations, and articles were included or excluded based on clinical relevance to robotic arthroplasty.
Results: The top 100 studies were cited a total of 5770 times from 1997 to 2021, with rapid growth in both citation generation and the number of articles published occurring in the past 5 years. The top 100 robotic arthroplasty articles originated from 12 countries, with the United States being responsible for almost half of the top 100. The most common study types were comparative studies (36) followed by case series (20), and the most common levels of evidence were III (23) and IV (33).
Conclusions: Research on robotic arthroplasty is rapidly growing and originates from a wide variety of countries, academic institutions, and with significant industry influence. This article serves as a reference to direct orthopaedic practitioners to the 100 most influential studies in robotic arthroplasty. We hope that these 100 studies and the analysis we provide aid healthcare professionals in efficiently assessing consensus, trends, and needs within the field.

Introduction

Robotic-assisted orthopaedic surgery has been implemented in the clinical setting for roughly 25 years [1]. In contrast to soft-tissue robotic surgical systems, robotics in orthopaedic surgery has focused on advancing the precision and accuracy of surgical manipulation of hard tissue by correlating preoperative imaging with bony landmarks [2–4]. The implementation of robotics has gained increasing attention, particularly in the field of joint arthroplasty, where semiactive computer navigation combined with haptic and/or visual feedback may allow for improved reproducibility and precision in osteotomy placement, joint alignment, and soft tissue balancing [1,2,5]. Robotic assistance also presents trade-offs of increased intraoperative times and technique complexity with increased accuracy of component position [1,6–8]. However, the evidence is variable as to whether robotic-assisted arthroplasty translates to improvements in clinical outcomes [9–11].

The use of robotics in arthroplasty has increased substantially in prevalence as well as in surgeon and patient interest [10,12]. A recent review of the Nationwide Inpatient Sample demonstrated that robotic and technology-assisted total knee arthroplasties have steadily increased from 1.2% in 2005 to 7.0% in 2014 [10,13]. As the body of literature on robotic arthroplasty continues to expand, developing a comprehensive understanding of the topic becomes increasingly difficult. It is beneficial for orthopaedic residents, fellows, and surgeons to be able to prioritize the most important

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studies. Fortunately, bibliometric analyses are a well-established tool to elicit common themes and to analyze how the trends of a particular field are evolving [14–16]. Bibliometric analyses synthesize citation impact as well as other research power indicators to identify high-impact articles and their relative effect on a specific field [16–18]. Furthermore, they allow researchers and clinicians to differentiate the areas or topics well-established in the literature from those that may need further investigation and inquiry. Within orthopaedics, bibliometric citation analyses have been conducted on a whole host of topics including elbow surgery, ankle arthroplasty, sports-related concussions, shoulder arthroscopy, total hip arthroplasty, and unicondylar knee arthroplasty [18–24]. In the field of orthopaedic robotics use, a particular citation analysis by Li et al. [4] used bibliometrics to assess the status and trends of robotics used across the entirety of orthopaedic surgery; however, only 72 (32%) of its papers focused on the area of arthroplasty. Therefore, a dedicated bibliometric analysis becomes more relevant as the specialized topic of robotic arthroplasty continues to expand in utilization and prevalence.

The purpose of this study was to objectively identify the 100 most influential studies in the robotic arthroplasty literature and to conduct a bibliometric analysis of these studies to describe their key characteristics. Additionally, the authors hypothesized that the year of publication would influence the number of citations the article was able to accrue.

Material and methods

This study was exempt from institutional review board approval due to the public nature of the data. Data and Metrics were obtained using the Clarivate Analytics Web of Knowledge database using study methods based on similar bibliometric analyses of orthopaedic literature [25–32]. The literature search was performed on May 3rd, 2022 using multiple Boolean queries to capture all iterations of robotic arthroplasty research. The search was conducted with no restrictions on date, language, journal, or country of origin. This original query resulted in 1967 total articles.

The list of articles was then sorted in descending order by the number of citations per article. The titles and abstracts of these articles were reviewed to determine their relevance to robotic arthroplasty and subsequent inclusion in our study. To qualify for selection, the article must present information on surgical indications, descriptions of procedures, surgical outcomes, complications, or an analysis of robotic arthroplasty procedures. Furthermore, the study had to have a clinical focus and involve patient subjects or review articles involving patient subjects. Manuscripts centered on wet lab, cadaveric, and animal studies were excluded. If there was ambiguity regarding whether a study should be included, the full article was examined by 2 independent authors (S.B. and M.L.M.) to make a final decision on inclusion or exclusion. If there was still a question as to whether an article should be included, the senior author (J.S.B.) was consulted.

A total of 389 articles were reviewed before finalizing the 100 most-cited studies that satisfied the inclusion criteria. These 100 studies were then reviewed to extract the following information: total number of citations per article, authors, publication year, country of origin, institution of origin, journal of publication, joint undergoing arthroplasty (shoulder, elbow, hip, knee, or ankle), name or brand of primary robotic device in the study, and any industry funding or affiliation associated with the study. Country of origin and affiliated institution of both the first and last authors were collected. In addition, the reviewer classified articles based on study design (randomized controlled trial, comparative study, case series, review article, descriptive article, cost analysis, or expert opinion) and level of evidence using the guidelines published in The Journal of Bone and Joint Surgery [33]. The level of evidence in a study indicates the relative risk of bias, rather than its quality. Both the study design and level of evidence were determined by a consensus opinion between the first and second authors (S.B. and M.L.M.).

The “comparative study” label was inclusive of prospective cohort studies, retrospective cohort studies, and case-control series. The label “review article” was inclusive of systematic reviews and meta-analyses that analyzed literature present in the field. If an article reviewed the literature without a clear methodology or systematic approach, it was classified with the “expert opinion” label. The “descriptive article” label was reserved for studies that primarily explored a specific robotic arthroplasty device or surgical technique involving a robotic arthroplasty device and minimally involved patient trials or reviews of patient trials. The citation density was calculated for each article by taking the total number of citations per year divided by the number of years since publication [15]. Clinical summaries were obtained for each study through consensus by having 2 reviewers extract the main results and conclusions from each study’s abstract and manuscript.

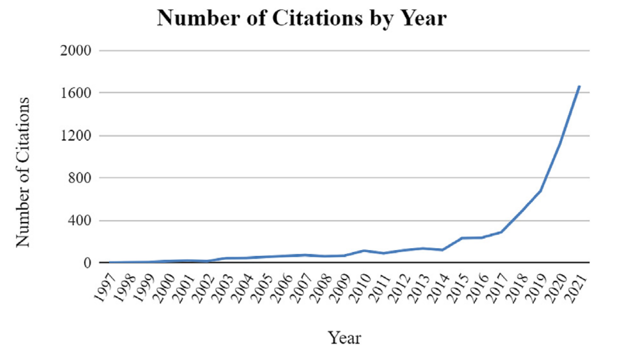

Figure 1. The number of citations accrued by the top 100 most-cited robotic arthroplasty studies over time.

Results

Of the top 100 most-cited papers in robotic arthroplasty, the oldest article was published in 1995, and the most recent article was published in 2021. The greatest number of articles were published in 2019 (16), and the second greatest number of articles were published in 2018 (15). The majority of studies were published after 2015 (59/100). (Fig. 1) The 100 included articles accumulated a total of 6052 citations at the time of analysis. As a whole, the citation

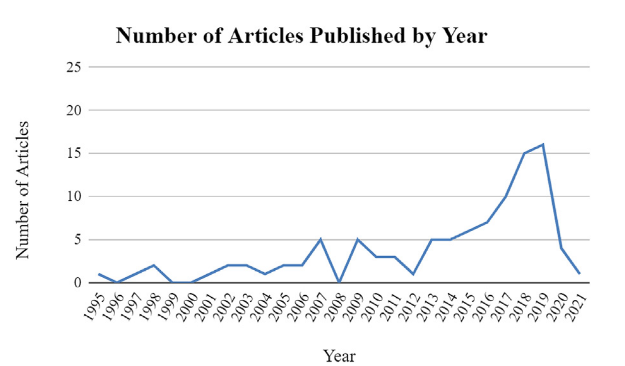

Figure 2. The number of top 100 most-cited robotic arthroplasty studies published by year.

Table 1
The top-100 most-cited robotic arthroplasty articles.

Rank	Article	No. of citations (citation density[a])	Original publication year
1	Bargar WL, Bauer A, Börner M. Primary and revision total hip replacement using the Robodoc system. Clin Orthop Relat Res 1998:82–91. https://doi.org/10.1097/00003086-199809000-00011.	236 (9.83)	1998
2	Cobb J, Henckel J, Gomes P, Harris S, Jakopec M, Rodriguez F, et al. Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the acrobot system. J Bone Joint Surg Br 2006;88:188–97. https://doi.org/10.1302/0301-620X.88B2.17220.	205 (12.81)	2006
3	Delp SL, Stulberg SD, Davies B, Picard F, Leitner F. Computer assisted knee replacement. Clin Orthop Relat Res 1998:49–56. https://doi.org/10.1097/00003086-199809000-00007.	167 (6.96)	1998
4	Jacofsky DJ, Allen M. Robotics in Arthroplasty: A Comprehensive Review. J Arthroplasty 2016;31:2353–63. https://doi.org/10.1016/j.arth.2016.05.026.	147 (24.50)	2016
5	Bell SW, Anthony I, Jones B, MacLean A, Rowe P, Blyth M. Improved Accuracy of Component Positioning with Robotic-Assisted Unicompartmental Knee Arthroplasty: Data from a Prospective, Randomized Controlled Study. J Bone Joint Surg Am 2016;98:627–35. https://doi.org/10.2106/JBJS.15.00664.	144 (24.00)	2016
6	Siebert W, Mai S, Kober R, Heeckt PF. Technique and first clinical results of robot-assisted total knee replacement. Knee 2002;9:173–80. https://doi.org/10.1016/s0968-0160(02)00015-7.	144 (7.20)	2002
7	Song E-K, Seon J-K, Yim J-H, Netravali NA, Bargar WL. Robotic-assisted TKA reduces postoperative alignment outliers and improves gap balance compared to conventional TKA. Clin Orthop Relat Res 2013;471:118–26. https://doi.org/10.1007/s11999-012-2407-3.	138 (15.33)	2013
8	Honl M, Dierk O, Gauck C, Carrero V, Lampe F, Dries S, et al. Comparison of robotic-assisted and manual implantation of a primary total hip replacement. A prospective study. J Bone Joint Surg Am 2003;85:1470–8. https://doi.org/10.2106/00004623-200308000-00007.	134 (7.05)	2003
9	Domb BG, El Bitar YF, Sadik AY, Stake CE, Botser IB. Comparison of robotic-assisted and conventional acetabular cup placement in THA: a matched-pair controlled study. Clin Orthop Relat Res 2014;472:329–36. https://doi.org/10.1007/s11999-013-3253-7.	127 (15.88)	2014
10	Lonner JH, John TK, Conditt MA. Robotic arm-assisted UKA improves tibial component alignment: a pilot study. Clin Orthop Relat Res 2010;468:141–6. https://doi.org/10.1007/s11999-009-0977-5.	124 (10.33)	2010
11	Jakopec M, Harris SJ, Rodriguez y Baena F, Gomes P, Cobb J, Davies BL. The first clinical application of a "hands-on" robotic knee surgery system. Comput Aided Surg 2001;6:329–39. https://doi.org/10.1002/igs.10023.	118 (5.62)	2001
12	Song E-K, Seon J-K, Park S-J, Jung WB, Park H-W, Lee GW. Simultaneous bilateral total knee arthroplasty with robotic and conventional techniques: a prospective, randomized study. Knee Surg Sports Traumatol Arthrosc 2011;19:1069–76. https://doi.org/10.1007/s00167-011-1400-9.	112 (10.18)	2011
13	Lang JE, Mannava S, Floyd AJ, Goddard MS, Smith BP, Mofidi A, et al. Robotic systems in orthopaedic surgery. J Bone Joint Surg Br 2011;93:1296–9. https://doi.org/10.1302/0301-620X.93B10.27418.	106 (9.64)	2011
14	Park SE, Lee CT. Comparison of robotic-assisted and conventional manual implantation of a primary total knee arthroplasty. J Arthroplasty 2007;22:1054–9. https://doi.org/10.1016/j.arth.2007.05.036.	106 (7.07)	2007
15	Kayani B, Konan S, Tahmassebi J, Pietrzak JRT, Haddad FS. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: a prospective cohort study. Bone Joint J 2018;100-B:930–7. https://doi.org/10.1302/0301-620X.100B7.BJJ-2017-1449.R1.	104 (26.00)	2018
16	Liow MHL, Xia Z, Wong MK, Tay KJ, Yeo SJ, Chin PL. Robot-assisted total knee arthroplasty accurately restores the joint line and mechanical axis. A prospective randomised study. J Arthroplasty 2014;29:2373–7. https://doi.org/10.1016/j.arth.2013.12.010.	98 (12.25)	2014
17	Pearle AD, O'Loughlin PF, Kendoff DO. Robot-assisted unicompartmental knee arthroplasty. J Arthroplasty 2010;25:230–7. https://doi.org/10.1016/j.arth.2008.09.024.	98 (8.17)	2010
18	Bellemans J, Vandenneucker H, Vanlauwe J. Robot-assisted total knee arthroplasty. Clin Orthop Relat Res 2007;464:111–6. https://doi.org/10.1097/BLO.0b013e318126c0c0.	92 (6.13)	2007
19	Schulz AP, Seide K, Queitsch C, von Haugwitz A, Meiners J, Kienast B, et al. Results of total hip replacement using the Robodoc surgical assistant system: clinical outcome and evaluation of complications for 97 procedures. Int J Med Robot 2007;3:301–6. https://doi.org/10.1002/rcs.161.	91 (6.07)	2007
20	Jakopec M, Rodriguez y Baena F, Harris SJ, Gomes P, Cobb J, Davies BL. The hands-on orthopaedic robot "acrobot": Early clinical trials of total knee replacement surgery. IEEE Transactions on Robotics and Automation 2003;19:902–11. https://doi.org/10.1109/TRA.2003.817510.	90 (4.74)	2003
21	Dunbar NJ, Roche MW, Park BH, Branch SH, Conditt MA, Banks SA. Accuracy of dynamic tactile-guided unicompartmental knee arthroplasty. J Arthroplasty 2012;27:803-808.e1. https://doi.org/10.1016/j.arth.2011.09.021.	86 (8.60)	2012
22	Sugano N. Computer-assisted orthopaedic surgery and robotic surgery in total hip arthroplasty. Clin Orthop Surg 2013;5:1–9. https://doi.org/10.4055/cios.2013.5.1.1.	79 (8.78)	2013
23	Pearle AD, van der List JP, Lee L, Coon TM, Borus TA, Roche MW. Survivorship and patient satisfaction of robotic-assisted medial unicompartmental knee arthroplasty at a minimum 2-year follow-up. Knee 2017;24:419–28. https://doi.org/10.1016/j.knee.2016.12.001.	78 (15.60)	2017
24	Kayani B, Konan S, Huq SS, Tahmassebi J, Haddad FS. Robotic-arm assisted total knee arthroplasty has a learning curve of seven cases for integration into the surgical workflow but no learning curve effect for accuracy of implant positioning. Knee Surg Sports Traumatol Arthrosc 2019;27:1132–41. https://doi.org/10.1007/s00167-018-5138-5.	72 (24.00)	2019
25	Blyth MJG, Anthony I, Rowe P, Banger MS, MacLean A, Jones B. Robotic arm-assisted versus conventional unicompartmental knee arthroplasty: Exploratory secondary analysis of a randomised controlled trial. Bone Joint Res 2017;6:631–9. https://doi.org/10.1302/2046-3758.611.BJR-2017-0060.R1.	72 (14.40)	2017
26	Marchand RC, Sodhi N, Khlopas A, Sultan AA, Harwin SF, Malkani AL, et al. Patient Satisfaction Outcomes after Robotic Arm-Assisted Total Knee Arthroplasty: A Short-Term Evaluation. J Knee Surg 2017;30:849–53. https://doi.org/10.1055/s-0037-1607450.	71 (14.20)	2017
27	Moschetti WE, Konopka JF, Rubash HE, Genuario JW. Can Robot-Assisted Unicompartmental Knee Arthroplasty Be Cost-Effective? A Markov Decision Analysis. J Arthroplasty 2016;31:759–65. https://doi.org/10.1016/j.arth.2015.10.018.	71 (11.83)	2016

(continued on next page)

Table 1 (*continued*)

Rank	Article	No. of citations (citation density[a])	Original publication year
28	Nakamura N, Sugano N, Nishii T, Kakimoto A, Miki H. A comparison between robotic-assisted and manual implantation of cementless total hip arthroplasty. Clin Orthop Relat Res 2010;468:1072–81. https://doi.org/10.1007/s11999-009-1158-2.	69 (5.75)	2010
29	Batailler C, White N, Ranaldi FM, Neyret P, Servien E, Lustig S. Improved implant position and lower revision rate with robotic-assisted unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2019;27:1232–40. https://doi.org/10.1007/s00167-018-5081-5.	68 (22.67)	2019
30	Plate JF, Mofidi A, Mannava S, Smith BP, Lang JE, Poehling GG, et al. Achieving accurate ligament balancing using robotic-assisted unicompartmental knee arthroplasty. Adv Orthop 2013;2013:837167. https://doi.org/10.1155/2013/837167.	67 (7.44)	2013
31	Sodhi N, Khlopas A, Piuzzi NS, Sultan AA, Marchand RC, Malkani AL, et al. The Learning Curve Associated with Robotic Total Knee Arthroplasty. J Knee Surg 2018;31:17–21.	66 (16.50)	2018
32	Kayani B, Konan S, Pietrzak JRT, Haddad FS. Iatrogenic Bone and Soft Tissue Trauma in Robotic-Arm Assisted Total Knee Arthroplasty Compared With Conventional Jig-Based Total Knee Arthroplasty: A Prospective Cohort Study and Validation of a New Classification System. J Arthroplasty 2018;33:2496–501. https://doi.org/10.1016/j.arth.2018.03.042.	65 (16.25)	2018
33	Liow MHL, Goh GS-H, Wong MK, Chin PL, Tay DK-J, Yeo S-J. Robotic-assisted total knee arthroplasty may lead to improvement in quality-of-life measures: a 2-year follow-up of a prospective randomized trial. Knee Surg Sports Traumatol Arthrosc 2017;25:2942–51. https://doi.org/10.1007/s00167-016-4076-3.	65 (13.00)	2017
34	Kayani B, Konan S, Pietrzak JRT, Huq SS, Tahmassebi J, Haddad FS. The learning curve associated with robotic-arm assisted unicompartmental knee arthroplasty: a prospective cohort study. Bone Joint J 2018;100-B:1033–42. https://doi.org/10.1302/0301-620X.100B8.BJJ-2018-0040.R1.	64 (16.00)	2018
35	Kayani B, Konan S, Tahmassebi J, Rowan FE, Haddad FS. An assessment of early functional rehabilitation and hospital discharge in conventional vs robotic-arm assisted unicompartmental knee arthroplasty: a prospective cohort study. Bone Joint J 2019;101-B:24–33. https://doi.org/10.1302/0301-620X.101B1.BJJ-2018-0564.R2.	61 (20.33)	2019
36	Domb BG, Redmond JM, Louis SS, Alden KJ, Daley RJ, LaReau JM, et al. Accuracy of Component Positioning in 1980 Total Hip Arthroplasties: A Comparative Analysis by Surgical Technique and Mode of Guidance. J Arthroplasty 2015;30:2208–18. https://doi.org/10.1016/j.arth.2015.06.059.	60 (8.57)	2015
37	Gilmour A, MacLean AD, Rowe PJ, Banger MS, Donnelly I, Jones BG, et al. Robotic-Arm-Assisted vs Conventional Unicompartmental Knee Arthroplasty. The 2-Year Clinical Outcomes of a Randomized Controlled Trial. J Arthroplasty 2018;33:S109–15. https://doi.org/10.1016/j.arth.2018.02.050.	59 (14.75)	2018
38	Kazanzides P, Mittelstadt BD, Musits BL, Bargar WL, Zuhars JF, Williamson B, et al. An integrated system for cementless hip replacement. IEEE Engineering in Medicine and Biology Magazine 1995;14:307–13. https://doi.org/10.1109/51.391772.	57 (2.11)	1995
39	Herry Y, Batailler C, Lording T, Servien E, Neyret P, Lustig S. Improved joint-line restitution in unicompartmental knee arthroplasty using a robotic-assisted surgical technique. Int Orthop 2017;41:2265–71. https://doi.org/10.1007/s00264-017-3633-9.	55 (11.00)	2017
40	Nishihara S, Sugano N, Nishii T, Miki H, Nakamura N, Yoshikawa H. Comparison between hand rasping and robotic milling for stem implantation in cementless total hip arthroplasty. J Arthroplasty 2006;21:957–66. https://doi.org/10.1016/j.arth.2006.01.001.	52 (3.25)	2006
41	Decking J, Theis C, Achenbach T, Roth E, Nafe B, Eckardt A. Robotic total knee arthroplasty: the accuracy of CT-based component placement. Acta Orthop Scand 2004;75:573–9. https://doi.org/10.1080/00016470410001448.	50 (2.78)	2004
42	Yang HY, Seon JK, Shin YJ, Lim HA, Song EK. Robotic Total Knee Arthroplasty with a Cruciate-Retaining Implant: A 10-Year Follow-up Study. Clin Orthop Surg 2017;9:169–76. https://doi.org/10.4055/cios.2017.9.2.169.	48 (9.60)	2017
43	Ilgen RL, Bukowski BR, Abiola R, Anderson P, Chughtai M, Khlopas A, et al. Robotic-Assisted Total Hip Arthroplasty: Outcomes at Minimum Two-Year Follow-Up. Surg Technol Int 2017;30:365–72.	47 (9.40)	2017
44	Plate JF, Augart MA, Seyler TM, Bracey DN, Hoggard A, Akbar M, et al. Obesity has no effect on outcomes following unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2017;25:645–51. https://doi.org/10.1007/s00167-015-3597-5.	47 (9.40)	2017
45	Swank ML, Alkire M, Conditt M, Lonner JH. Technology and cost-effectiveness in knee arthroplasty: computer navigation and robotics. Am J Orthop (Belle Mead NJ) 2009;38:32–6.	47 (3.62)	2009
46	Hansen DC, Kusuma SK, Palmer RM, Harris KB. Robotic guidance does not improve component position or short-term outcome in medial unicompartmental knee arthroplasty. J Arthroplasty 2014;29:1784–9. https://doi.org/10.1016/j.arth.2014.04.012.	46 (5.75)	2014
47	Kayani B, Konan S, Ayuob A, Onochie E, Al-Jabri T, Haddad FS. Robotic technology in total knee arthroplasty: a systematic review. EFORT Open Rev 2019;4:611–7. https://doi.org/10.1302/2058-5241.4.190022.	45 (15.00)	2019
48	Kleeblad LJ, Borus TA, Coon TM, Dounchis J, Nguyen JT, Pearle AD. Midterm Survivorship and Patient Satisfaction of Robotic-Arm-Assisted Medial Unicompartmental Knee Arthroplasty: A Multicenter Study. J Arthroplasty 2018;33:1719–26. https://doi.org/10.1016/j.arth.2018.01.036.	45 (11.25)	2018
49	Kamara E, Robinson J, Bas MA, Rodriguez JA, Hepinstall MS. Adoption of Robotic vs Fluoroscopic Guidance in Total Hip Arthroplasty: Is Acetabular Positioning Improved in the Learning Curve? J Arthroplasty 2017;32:125–30. https://doi.org/10.1016/j.arth.2016.06.039.	45 (9.00)	2017
50	Nodzo SR, Chang C-C, Carroll KM, Barlow BT, Banks SA, Padgett DE, et al. Intraoperative placement of total hip arthroplasty components with robotic-arm assisted technology correlates with postoperative implant position: a CT-based study. Bone Joint J 2018;100-B:1303–9. https://doi.org/10.1302/0301-620X.100B10-BJJ-2018-0201.R1.	44 (11.00)	2018
51	Chun YS, Kim KI, Cho YJ, Kim YH, Yoo MC, Rhyu KH. Causes and patterns of aborting a robot-assisted arthroplasty. J Arthroplasty 2011;26:621–5. https://doi.org/10.1016/j.arth.2010.05.017.	44 (4.00)	2011
52	Kim Y-H, Yoon S-H, Park J-W. Does Robotic-assisted TKA Result in Better Outcome Scores or Long-Term Survivorship Than Conventional TKA? A Randomized, Controlled Trial. Clin Orthop Relat Res 2020;478:266–75. https://doi.org/10.1097/CORR.0000000000000916.	43 (21.50)	2020
53	Redmond JM, Gupta A, Hammarstedt JE, Petrakos AE, Finch NA, Domb BG. The learning curve associated with robotic-assisted total hip arthroplasty. J Arthroplasty 2015;30:50–4. https://doi.org/10.1016/j.arth.2014.08.003.	43 (6.14)	2015
54	Roche M, O'Loughlin PF, Kendoff D, Musahl V, Pearle AD. Robotic arm-assisted unicompartmental knee arthroplasty: preoperative planning and surgical technique. Am J Orthop (Belle Mead NJ) 2009;38:10–5.	42 (3.23)	2009

Table 1 (*continued*)

Rank	Article	No. of citations (citation density[a])	Original publication year
55	Marchand RC, Sodhi N, Khlopas A, Sultan AA, Higuera CA, Stearns KL, et al. Coronal Correction for Severe Deformity Using Robotic-Assisted Total Knee Arthroplasty. J Knee Surg 2018;31:2–5. https://doi.org/10.1055/s-0037-1608840.	41 (10.25)	2018
56	Jeon S-W, Kim K-I, Song SJ. Robot-Assisted Total Knee Arthroplasty Does Not Improve Long-Term Clinical and Radiologic Outcomes. J Arthroplasty 2019;34:1656–61. https://doi.org/10.1016/j.arth.2019.04.007.	40 (13.33)	2019
57	Cho K-J, Seon J-K, Jang W-Y, Park C-G, Song E-K. Robotic vs conventional primary total knee arthroplasty: clinical and radiological long-term results with a minimum follow-up of 10 years. Int Orthop 2019;43:1345–54. https://doi.org/10.1007/s00264-018-4231-1.	40 (13.33)	2019
58	Dretakis K, Igoumenou VG. Outcomes of robotic-arm-assisted medial unicompartmental knee arthroplasty: minimum 3-year follow-up. Eur J Orthop Surg Traumatol 2019;29:1305–11. https://doi.org/10.1007/s00590-019-02424-4.	40 (3.07)	2009
59	Börner M, Bauer A, Lahmer A. Computer-guided robot-assisted hip endoprosthesis. Orthopade 1997;26:251–7. https://doi.org/10.1007/s001320050092.	40 (1.6)	1997
60	Boylan M, Suchman K, Vigdorchik J, Slover J, Bosco J. Technology-Assisted Hip and Knee Arthroplasties: An Analysis of Utilization Trends. J Arthroplasty 2018;33:1019–23. https://doi.org/10.1016/j.arth.2017.11.033.	38 (9.50)	2018
61	Liow MHL, Chin PL, Tay KJD, Chia SL, Lo NN, Yeo SJ. Early experiences with robot-assisted total knee arthroplasty using the DigiMatch ROBODOC surgical system. Singapore Med J 2014;55:529–34. https://doi.org/10.11622/smedj.2014136.	38 (4.75)	2014
62	Lonner JH. Indications for unicompartmental knee arthroplasty and rationale for robotic arm-assisted technology. Am J Orthop (Belle Mead NJ) 2009;38:3–6.	38 (2.92)	2009
63	Pearle AD, Kendoff D, Stueber V, Musahl V, Repicci JA. Perioperative management of unicompartmental knee arthroplasty using the MAKO robotic arm system (MAKOplasty). Am J Orthop (Belle Mead NJ) 2009;38:16–9.	38 (2.92)	2009
64	Thienpont E, Fennema P, Price A. Can technology improve alignment during knee arthroplasty. Knee 2013;20 Suppl 1:S21-28. https://doi.org/10.1016/S0968-0160(13)70005-X.	37 (4.11)	2013
65	Kanawade V, Dorr LD, Banks SA, Zhang Z, Wan Z. Precision of robotic guided instrumentation for acetabular component positioning. J Arthroplasty 2015;30:392–7. https://doi.org/10.1016/j.arth.2014.10.021.	36 (5.14)	2015
66	Banerjee S, Cherian JJ, Elmallah RK, Jauregui JJ, Pierce TP, Mont MA. Robotic-assisted knee arthroplasty. Expert Rev Med Devices 2015;12:727–35. https://doi.org/10.1586/17434440.2015.1086264.	36 (5.14)	2015
67	Hananouchi T, Sugano N, Nishii T, Nakamura N, Miki H, Kakimoto A, et al. Effect of robotic milling on periprosthetic bone remodeling. J Orthop Res 2007;25:1062–9. https://doi.org/10.1002/jor.20376.	36 (2.40)	2007
68	Marchand RC, Sodhi N, Anis HK, Ehiorobo J, Newman JM, Taylor K, et al. One-Year Patient Outcomes for Robotic-Arm-Assisted vs Manual Total Knee Arthroplasty. J Knee Surg 2019;32:1063–8. https://doi.org/10.1055/s-0039-1683977.	35 (11.67)	2019
69	Cool CL, Jacofsky DJ, Seeger KA, Sodhi N, Mont MA. A 90-day episode-of-care cost analysis of robotic-arm assisted total knee arthroplasty. J Comp Eff Res 2019;8:327–36. https://doi.org/10.2217/cer-2018-0136.	35 (11.67)	2019
70	Khlopas A, Sodhi N, Sultan AA, Chughtai M, Molloy RM, Mont MA. Robotic Arm-Assisted Total Knee Arthroplasty. J Arthroplasty 2018;33:2002–6. https://doi.org/10.1016/j.arth.2018.01.060.	35 (8.75)	2018
71	Mofidi A, Plate JF, Lu B, Conditt MA, Lang JE, Poehling GG, et al. Assessment of accuracy of robotically assisted unicompartmental arthroplasty. Knee Surg Sports Traumatol Arthrosc 2014;22:1918–25. https://doi.org/10.1007/s00167-014-2969-6.	35 (4.37)	2014
72	Davies BL, Rodriguez y Baena FM, Barrett ARW, Gomes MPSF, Harris SJ, Jakopec M, et al. Robotic control in knee joint replacement surgery. Proc Inst Mech Eng H 2007;221:71–80. https://doi.org/10.1243/09544119JEIM250.	35 (2.33)	2007
73	Canetti R, Batailler C, Bankhead C, Neyret P, Servien E, Lustig S. Faster return to sport after robotic-assisted lateral unicompartmental knee arthroplasty: a comparative study. Arch Orthop Trauma Surg 2018;138:1765–71. https://doi.org/10.1007/s00402-018-3042-6.	34 (8.50)	2018
74	Antonios JK, Korber S, Sivasundaram L, Mayfield C, Kang HP, Oakes DA, et al. Trends in computer navigation and robotic assistance for total knee arthroplasty in the United States: an analysis of patient and hospital factors. Arthroplasty Today 2019;5:88–95. https://doi.org/10.1016/j.artd.2019.01.002.	33 (11.00)	2019
75	van der List JP, Chawla H, Joskowicz L, Pearle AD. Current state of computer navigation and robotics in unicompartmental and total knee arthroplasty: a systematic review with meta-analysis. Knee Surg Sports Traumatol Arthrosc 2016;24:3482–95. https://doi.org/10.1007/s00167-016-4305-9.	33 (5.50)	2016
76	Rodriguez F, Harris S, Jakopec M, Barrett A, Gomes P, Henckel J, et al. Robotic clinical trials of uni-condylar arthroplasty. The International Journal of Medical Robotics and Computer Assisted Surgery 2005;1:20–8. https://doi.org/10.1002/rcs.52.	33 (1.94)	2005
77	Bukowski BR, Anderson P, Khlopas A, Chughtai M, Mont MA, Illgen RL. Improved Functional Outcomes with Robotic Compared with Manual Total Hip Arthroplasty. Surg Technol Int 2016;29:303–8.	32 (5.33)	2016
78	Clement ND, Deehan DJ, Patton JT. Robot-assisted unicompartmental knee arthroplasty for patients with isolated medial compartment osteoarthritis is cost-effective: a Markov decision analysis. Bone Joint J 2019;101-B:1063–70. https://doi.org/10.1302/0301-620X.101B9.BJJ-2018-1658.R1.	31 (10.33)	2019
79	Robinson PG, Clement ND, Hamilton D, Blyth MJG, Haddad FS, Patton JT. A systematic review of robotic-assisted unicompartmental knee arthroplasty: prosthesis design and type should be reported. Bone Joint J 2019;101-B:838–47. https://doi.org/10.1302/0301-620X.101B7.BJJ-2018-1317.R1.	31 (10.33)	2019
80	Lonner JH, Fillingham YA. Pros and Cons: A Balanced View of Robotics in Knee Arthroplasty. J Arthroplasty 2018;33:2007–13. https://doi.org/10.1016/j.arth.2018.03.056.	31 (7.75)	2018
81	Bargar WL, Parise CA, Hankins A, Marlen NA, Campanelli V, Netravali NA. Fourteen Year Follow-Up of Randomized Clinical Trials of Active Robotic-Assisted Total Hip Arthroplasty. J Arthroplasty 2018;33:810–4. https://doi.org/10.1016/j.arth.2017.09.066.	31 (7.75)	2018
82	Netravali NA, Shen F, Park Y, Bargar WL. A perspective on robotic assistance for knee arthroplasty. Adv Orthop 2013;2013:970703. https://doi.org/10.1155/2013/970703.	31 (3.44)	2013
83	Siebel T, Käfer W. Clinical outcome following robotic assisted versus conventional total hip arthroplasty: a controlled and prospective study of seventy-one patients. Z Orthop Ihre Grenzgeb 2005;143:391–8. https://doi.org/10.1055/s-2005-836776.	31 (1.82)	2005
84	Bach CM, Winter P, Nogler M, Göbel G, Wimmer C, Ogon M. No functional impairment after Robodoc total hip arthroplasty. Acta Orthopaedica Scandinavica 2002;73:386–91. https://doi.org/10.1080/00016470216316.	31 (1.55)	2002

(*continued on next page*)

Table 1 (*continued*)

Rank	Article	No. of citations (citation density[a])	Original publication year
85	Sultan AA, Piuzzi N, Khlopas A, Chughtai M, Sodhi N, Mont MA. Utilization of robotic-arm assisted total knee arthroplasty for soft tissue protection. Expert Rev Med Devices 2017;14:925–7. https://doi.org/10.1080/17434440.2017.1392237.	30 (6.00)	2017
86	Elson L, Dounchis J, Illgen R, Marchand RC, Padgett DE, Bragdon CR, et al. Precision of acetabular cup placement in robotic integrated total hip arthroplasty. Hip Int 2015;25:531–6. https://doi.org/10.5301/hipint.5000289.	30 (4.29)	2015
87	Marchand RC, Sodhi N, Bhowmik-Stoker M, Scholl L, Condrey C, Khlopas A, et al. Does the Robotic Arm and Preoperative CT Planning Help with 3D Intraoperative Total Knee Arthroplasty Planning? J Knee Surg 2019;32:742–9. https://doi.org/10.1055/s-0038-1668122.	29 (9.67)	2019
88	Kayani B, Konan S, Thakrar RR, Huq SS, Haddad FS. Assuring the long-term total joint arthroplasty: a triad of variables. Bone Joint J 2019;101-B:11–8. https://doi.org/10.1302/0301-620X.101B1.BJJ-2018-0377.R1.	29 (9.67)	2019
89	Chen X, Xiong J, Wang P, Zhu S, Qi W, Peng H, et al. Robotic-assisted compared with conventional total hip arthroplasty: systematic review and meta-analysis. Postgrad Med J 2018;94:335–41. https://doi.org/10.1136/postgradmedj-2017-135352.	29 (7.25)	2018
90	Ren Y, Cao S, Wu J, Weng X, Feng B. Efficacy and reliability of active robotic-assisted total knee arthroplasty compared with conventional total knee arthroplasty: a systematic review and meta-analysis. Postgrad Med J 2019;95:125–33. https://doi.org/10.1136/postgradmedj-2018-136190.	28 (9.33)	2019
91	Tsai T-Y, Dimitriou D, Li J-S, Kwon Y-M. Does haptic robot-assisted total hip arthroplasty better restore native acetabular and femoral anatomy? Int J Med Robot 2016;12:288–95. https://doi.org/10.1002/rcs.1663.	28 (4.67)	2016
92	MacCallum KP, Danoff JR, Geller JA. Tibial baseplate positioning in robotic-assisted and conventional unicompartmental knee arthroplasty. Eur J Orthop Surg Traumatol 2016;26:93–8. https://doi.org/10.1007/s00590-015-1708-0.	28 (4.67)	2016
93	Gupta A, Redmond JM, Hammarstedt JE, Petrakos AE, Vemula SP, Domb BG. Does Robotic-Assisted Computer Navigation Affect Acetabular Cup Positioning in Total Hip Arthroplasty in the Obese Patient? A Comparison Study. J Arthroplasty 2015;30:2204–7. https://doi.org/10.1016/j.arth.2015.06.062.	28 (4.00)	2015
94	St Mart J-P, de Steiger RN, Cuthbert A, Donnelly W. The 3-year survivorship of robotically assisted vs non-robotically assisted unicompartmental knee arthroplasty. Bone Joint J 2020;102-B:319–28. https://doi.org/10.1302/0301-620X.102B3.BJJ-2019-0713.R1.	27 (13.50)	2020
95	Burger JA, Kleeblad LJ, Laas N, Pearle AD. Mid-term survivorship and patient-reported outcomes of robotic-arm assisted partial knee arthroplasty. Bone Joint J 2020;102-B:108–16. https://doi.org/10.1302/0301-620X.102B1.BJJ-2019-0510.R1.	27 (13.50)	2020
96	Sires JD, Craik JD, Wilson CJ. Accuracy of Bone Resection in MAKO Total Knee Robotic-Assisted Surgery. J Knee Surg 2021;34:745–8. https://doi.org/10.1055/s-0039-1700570.	26 (26.00)	2021
97	Khlopas A, Sodhi N, Hozack WJ, Chen AF, Mahoney OM, Kinsey T, et al. Patient-Reported Functional and Satisfaction Outcomes after Robotic-Arm-Assisted Total Knee Arthroplasty: Early Results of a Prospective Multicenter Investigation. J Knee Surg 2020;33:685–90. https://doi.org/10.1055/s-0039-1684014.	26 (13.00)	2020
98	Kayani B, Konan S, Ayuob A, Ayyad S, Haddad FS. The current role of robotics in total hip arthroplasty. EFORT Open Rev 2019;4:618–25. https://doi.org/10.1302/2058-5241.4.180088.	26 (8.67)	2019
99	Karunaratne S, Duan M, Pappas E, Fritsch B, Boyle R, Gupta S, et al. The effectiveness of robotic hip and knee arthroplasty on patient-reported outcomes: A systematic review and meta-analysis. Int Orthop 2019;43:1283–95. https://doi.org/10.1007/s00264-018-4140-3.	26 (8.67)	2019
100	Perets I, Walsh JP, Close MR, Mu BH, Yuen LC, Domb BG. Robot-assisted total hip arthroplasty: Clinical outcomes and complication rate. Int J Med Robot 2018;14:e1912. https://doi.org/10.1002/rcs.1912.	26 (6.50)	2018

[a] Number of citations per year since publication.

density for the 100 robotic arthroplasty studies grew steadily over the past 25 years, with a marked increase observed since 2016. (Fig. 2) A list of the top 100 most-cited papers with their authors, number of citations, citation density, and publication year is presented in Table 1 [Table 1].

The mean and median numbers of citations per article were 60.5 and 44.0, respectively. The top 3 articles by citation density had densities of 26.0, 26.0, and 24.5 [1,34,35]. The bottom 3 citation densities were 1.5, 1.6, and 1.8 [36–38]. The oldest published study was published in 1995 and ranked 38 out of 100 articles with 57 citations and a citation density of 2.1 [39].

The top 3 authors by number of published articles in the top 100 were Mont, Haddad, and Kayani with 11, 8, and 8 articles, respectively. The top 3 authors by total number of citations were Davies, Haddad, and Kayani with 481, 466, and 466, respectively. There were a total of 10 authors with 4 or more studies included in this list of the top 100 most-cited articles in robotic arthroplasty [Table 2].

Table 2
The most represented first and last authors among the top 100 robotic arthroplasty articles.

Author name	Number of first author publications	Number of last author publications	Number of articles included	Total number of citations	Average citations per publication
Mont, Michael A.	0	11	11	451	41.0
Haddad, Fares S.	0	8	8	466	58.3
Kayani, Babar	8	0	8	466	58.3
Pearle, Andrew D.	3	4	7	361	51.6
Davies, Brian L.	1	4	5	481	96.2
Domb, Benjamin G.	2	3	5	284	56.8
Bargar, William L.	2	2	4	436	109.0
Song, Eun-Kyoo	2	2	4	338	84.5
Lonner, Jess H.	3	1	4	240	60.0
Marchand, Robert C.	4	0	4	176	44.0

All authors with 4 or more first/last author publications included.

The included articles were published in 29 journals in the United States and internationally. The Journal of Arthroplasty, Journal of Bone and Joint Surgery, and Clinical Orthopaedics and Related Research published the greatest number of robotic arthroplasty studies with 22, 14, and 8 articles, respectively [Table 3]. These articles originated from 12 different countries, with the United States (49), United Kingdom (19), and Korea (8) having published the most articles (Fig. 3). A total of 14 different institutions produced 3 or more articles in the top 100, with University College London (8), Hospital for Special Surgery (7), and Cleveland Clinic (6) producing the most [Table 4]. The most common study types were comparative studies (36), followed by case series (20), and randomized controlled trials (15) [Table 5]. The most common level of evidence was type IV (33), followed by type III (23), and type II (17) (Fig. 4).

Of the 100 studies, 98 focused on a specific joint. Of these 98 focused studies, distribution of focus was as follows: 68 knee (69.4%), 27 hip (27.5%), and 3 both hip and knee (3.1%). None of the top 100 articles focused on shoulder, elbow, or ankle arthroplasty. Within the 68 articles focused on the knee joint, 38 centered on total knee arthroplasty (55.9%), 28 explored unicompartmental knee arthroplasty (41.2%), and 2 examined both total knee arthroplasty and unicompartmental knee arthroplasty (2.9%). In addition, 68 of the 100 articles utilized or examined a specific robotic device. The distribution of robotic device name or brand is as follows: 38 studies involved MAKO (55.9%), 20 studies involved ROBODOC (29.4%), 4 studies involved ACROBOT (5.9%), 3 studies involved CASPAR (4.4%), and 3 studies involved NAVIO (4.4%) [Table 6]. Eighty-nine of the 100 studies included information relating to funding or affiliation for the studies, revealing that 64 of the 89 (71.9%) studies were associated with and/or funded by industry.

The top 100 studies presented a variety of results and clinical findings [Table 7]. Most commonly, 37 studies found an improvement in radiographic outcomes and accuracy using robotic arthroplasty procedures when compared to conventional manual techniques, while 17 studies found an improvement in clinical outcomes when compared to conventional manual techniques. However, 19 studies found no difference in outcomes across robotic and conventional manual techniques, and 6 studies found worse outcomes with robotic techniques when compared to conventional manual techniques. Studies exploring the operating time, cost-effectiveness, and learning curve of the procedure also demonstrated mixed findings.

Discussion

The field of robotic arthroplasty is young and rapidly growing. The oldest article included in this analysis was published in 1995, representing only 27 years of research history. The novelty of this surgical technique within orthopaedic surgery is reflected by the fact that the 100 most influential studies in robotic arthroplasty are primarily composed of comparative studies (36) and case series (20) and are level IV (33) and III (23) evidence. This relatively short history of research and development likely explains the predominance of comparative studies and case series. However, a reasonable proportion of studies (15%) were randomized controlled trials. Despite the novelty of robotics in orthopaedic surgery, several high-level evidence studies have been published and serve as the foundation that has supported the expeditious adoption and growth of this surgical technique worldwide [10,40]. We postulate that more reports with level I evidence will emerge as the field of robotic arthroplasty continues to mature. Publication of high-quality studies will become increasingly important as the debate surrounding the cost-effectiveness and associated outcomes of robotic arthroplasty systems progresses [41]. For these platforms to continue their swift adoption and utilization growth, additional high-quality evidence in the form of randomized controlled trials with specific analyses of patient-reported outcomes will be necessary.

Notably, we observed an exponential rise in citation generation by year for the top 100 most influential papers in robotic arthroplasty (Fig. 2). Between 1997 and 2021, 5770 total citations were accumulated by these 100 articles. However, nearly one-half of these citations were generated in the past 2 years (2790 between 2020 and 2021), and over two-thirds of the citations were accumulated in the past 4 years (3940 between 2018 and 2021). While similar bibliometric analyses analyzing orthopaedic procedures such as knee arthroscopy, hip arthroscopy, total hip arthroplasty, and ankle arthroplasty found rapid growth in citation

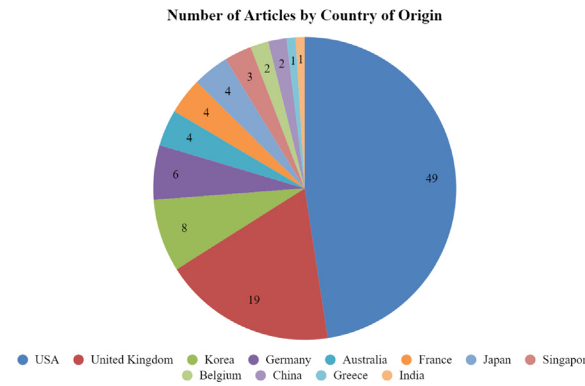

Figure 3. The number of the top 100 most-cited robotic arthroplasty studies originating from each country.

Table 3
The top 100 most-cited robotic arthroplasty journals of origin.

Journal name	Number of articles
Journal of Arthroplasty	22
Journal of Bone and Joint Surgery	14
Clinical Orthopaedics and Related Research	8
Journal of Knee Surgery	7
Knee Surgery, Sports Traumatology, Arthroscopy	7
American Journal of Orthopedics	5
International Journal of Medical Robotics and Computer Assisted Surgery	4
International Orthopaedics	3
Knee	3

All journals with 3 or more articles included.

Table 4
The top 100 most-cited robotic arthroplasty institutions of origin.

Institution name	Number of articles
University College London	8
Hospital for Special Surgery	7
Cleveland Clinic	6
American Hip Institute	5
Imperial College London	5
Chonnam National University	4
University of California, Davis School of Medicine	4
Lenox Hill Hospital	4
Osaka University Medical School	4
Ortho Rhode Island	4
Croix-Rousse Hospital	3
Glasgow Royal Infirmary	3
Singapore General Hospital	3
Wake Forest School of Medicine	3

All institutions with greater than 3 articles included.

Table 5
The top-100 most-cited robotic arthroplasty articles by study type.

Type of study	Number of articles
Randomized controlled trial	15
Comparative study	36
Case series	20
Review article	11
Cost analysis	4
Descriptive article	3
Expert opinion	11

Table 6
The top-100 most-cited robotic arthroplasty articles by robot name/brand.

Robot name/brand	Number of articles
ACROBOT	4
CASPAR	3
MAKO	38
NAVIO	3
ROBODOC	20

accumulation, no other topic areas have observed the same high rate of growth as seen in robotic arthroplasty [20,21,23,42]. The difference noted between this study and other similar bibliometric analyses regarding citation accumulation may be attributed to the novelty of this surgical technique. Commonly used orthopaedic techniques like arthroscopy and joint arthroplasty have been in existence for many decades [43,44]. However, robotically assisted arthroplasty has only been used for approximately 25 years [1] with more widespread adoption taking place in the past 10-20 years.

The country of origin of the top 100 most cited articles was quite varied, with the United States possessing the most publications (49). The United Kingdom had the second most with 19 publications, followed by Korea and Germany with 8 and 6, respectively. These findings are consistent with previous orthopaedic bibliometric analyses. Moore et al. and Murphy et al. found that within shoulder and knee arthroscopy research, the United States was responsible for 62% and 52% of article generation, respectively [21,42]. Additionally, Zhang et al. found that 37% of the top 100 most cited hip arthroplasty articles originated in the United States [23]. Similarly to other fields within orthopaedic surgery, the research generation for robotic arthroplasty has been a global effort led by the United States and supported by many other European and Asian countries.

Among the top 100 most influential robotic arthroplasty articles, a few specific institutions and authors were well represented. Specifically, the University College of London, the Hospital for Special Surgery, and the Cleveland Clinic were responsible for approximately 20% of all articles included. Institutional origin is likely to play a substantial role in the citation generation and subsequent influence an article has in its field. In a study by Abed et al., the authors found that the institution of origin and the prestige of an affiliated medical school or university were significantly correlated with citation generation and citation rate for orthopaedic sports medicine journals specifically [45]. This is evidenced in our analysis as well, with many highly prestigious institutions being responsible for several of the most influential robotic arthroplasty research items. However, it is difficult to determine causation in this situation. Perhaps prestige and reputation were less important for citation generation but allowed the authors access to high-quality data and resources to publish highly impactful research.

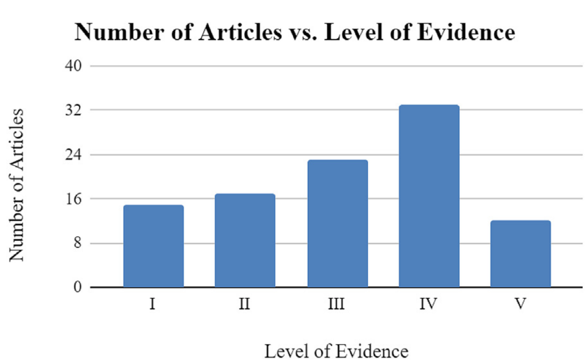

Figure 4. Categorization of the top 100 most-cited robotic arthroplasty studies by level of evidence.

The content of the articles included in this analysis was also quite varied. Regarding the joint of focus, 68 studies analyzed only the knee, 27 focused on only the hip, and 3 focused on both the knee and hip. Interestingly, no studies were included analyzing robotic ankle, shoulder, or elbow arthroplasty. While robotic arthroplasty technology exists for each of these joints, hip and knee arthroplasty comprise the vast majority of all arthroplasty procedures worldwide and are more readily studied. As robotic systems become more advanced, cheaper, and widespread, studies in these other arthroplasty procedures are anticipated.

Additionally, a total of 5 different robotic arthroplasty technology platforms were represented in the top 100 articles, with MAKO (38) being the most common. Currently, Stryker and their MAKO robotic arthroplasty system are the leaders in the robotic arthroplasty market due to their rapid expansion and growth to metropolitan surgical centers capable of purchasing their $1 million device [46]. However, as the technology continues to advance and becomes more ubiquitous, in addition to eventual patent expiration, new companies are likely to enter the market and may offer lower price points and different technological features.

Notably, 64 of 89 studies (71.9%) with relevant information available were associated with and/or funded by industry. This reveals how the industry has had a large influence on the research landscape of robotic arthroplasty thus far. We speculate that as robotic arthroplasty becomes less novel, more and more industry-independent studies will be conducted.

Finally, the clinical findings of the top 100 most-cited robotic arthroplasty studies indicate a predominating focus within the literature on improved radiographic outcomes when assessing robotic arthroplasty techniques. While other studies in the top 100 demonstrate mixed results, it is clear that more studies exploring long-term clinical outcomes with robotic arthroplasties are necessary to definitively evaluate this newer technique.

Limitations

This study has several limitations. First, while the selection criteria used to obtain the top 100 articles in robotic arthroplasty were well-defined and very comprehensive, they were partially subjective in nature. However, the authors maintained objectivity as much as possible in the review and selection of articles by having multiple authors involved in the selection process. Secondly, while citation accumulation is an important metric that can objectively assess an article's influence on a specific field, it is not the only factor that contributes to an article's impact. Other factors influencing citation frequency include research funding disparities, positive outcome bias, time since the publication date, institutional prestige, and dissemination bias. Therefore, articles with fewer total citations but a substantial impact on clinical and surgical practice may have been overlooked in the present analysis. However, total number of citations serves as an objective metric that can

Table 7
Clinical summaries of the top-100 most-cited robotic arthroplasty articles.

Rank	Article citation	Summary
1	Bargar WL, Bauer A, Börner M. Primary and revision total hip replacement using the Robodoc system. Clin Orthop Relat Res 1998:82–91. https://doi.org/10.1097/00003086-199809000-00011.	• The Robodoc system is suggested to be a safe and effective tool for performing both primary and revision THAs. • Results indicate superior implant fit and positioning with less risk of femoral fractures.
2	Cobb J, Henckel J, Gomes P, Harris S, Jakopec M, Rodriguez F, et al. Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the acrobot system. J Bone Joint Surg Br 2006;88:188–97. https://doi.org/10.1302/0301-620X.88B2.17220.	• The Acrobot system is suggested to be a safe and effective tool for hands-on robotic UKA. • Results indicate an improvement in accuracy and fewer complications.
3	Delp SL, Stulberg SD, Davies B, Picard F, Leitner F. Computer assisted knee replacement. Clin Orthop Relat Res 1998:49–56. https://doi.org/10.1097/00003086-199809000-00007.	• Computer-assisted TKA techniques allow for more precise preoperative planning and intraoperative control, resulting in improved outcomes and fewer complications.
4	Jacofsky DJ, Allen M. Robotics in Arthroplasty: A Comprehensive Review. J Arthroplasty 2016;31:2353–63. https://doi.org/10.1016/j.arth.2016.05.026.	• Use of robotic technology has shown an increase in production capacity, precision, and lower cost. • Robotic arthroplasty systems have demonstrated improved accuracy of placement, improved satisfaction, and reduced complications.
5	Bell SW, Anthony I, Jones B, MacLean A, Rowe P, Blyth M. Improved Accuracy of Component Positioning with Robotic-Assisted Unicompartmental Knee Arthroplasty: Data from a Prospective, Randomized Controlled Study. J Bone Joint Surg Am 2016;98:627–35. https://doi.org/10.2106/JBJS.15.00664.	• Robotic-assisted UKA with the MAKO RIO system demonstrated improved accuracy of implant positioning when compared to conventional techniques.
6	Siebert W, Mai S, Kober R, Heeckt PF. Technique and first clinical results of robot-assisted total knee replacement. Knee 2002;9:173–80. https://doi.org/10.1016/s0968-0160(02)00015-7.	• Robot-assisted TKA demonstrates an ability to execute a highly precise preoperative plan based on computed tomography (CT) scans. • Robot-assisted TKA demonstrates better alignment of prosthetic components and improved bone-implant fit.
7	Song E-K, Seon J-K, Yim J-H, Netravali NA, Bargar WL. Robotic-assisted TKA reduces postoperative alignment outliers and improves gap balance compared to conventional TKA. Clin Orthop Relat Res 2013;471:118–26. https://doi.org/10.1007/s11999-012-2407-3.	• Robotic-assisted TKA is shown to reduce mechanical axis alignment outliers and improve flexion-extension gap balance. • There were no notable differences in clinical scores or complications when compared to conventional techniques.
8	Honl M, Dierk O, Gauck C, Carrero V, Lampe F, Dries S, et al. Comparison of robotic-assisted and manual implantation of a primary total hip replacement. A prospective study. J Bone Joint Surg Am 2003;85:1470–8. https://doi.org/10.2106/00004623-200308000-00007.	• Advantages of robotic-assisted technology were improved preoperative planning and accuracy of the intraoperative procedure. • Disadvantages of robotic-assisted technology were high revision rate, muscle damage, dislocation rate, and longer duration of surgery.
9	Domb BG, El Bitar YF, Sadik AY, Stake CE, Botser IB. Comparison of robotic-assisted and conventional acetabular cup placement in THA: a matched-pair controlled study. Clin Orthop Relat Res 2014;472:329–36. https://doi.org/10.1007/s11999-013-3253-7.	• Robotic-assisted technique in THA led to improvement in placement of acetabular cup placement.
10	Lonner JH, John TK, Conditt MA. Robotic arm-assisted UKA improves tibial component alignment: a pilot study. Clin Orthop Relat Res 2010;468:141–6. https://doi.org/10.1007/s11999-009-0977-5.	• Robotic arm-assisted UKA reduced alignment errors of the tibial component.
11	Jakopec M, Harris SJ, Rodriguez y Baena F, Gomes P, Cobb J, Davies BL. The first clinical application of a "hands-on" robotic knee surgery system. Comput Aided Surg 2001;6:329–39. https://doi.org/10.1002/igs.10023.	• The Acrobot system was used to successfully register and cut knee bones in TKA, demonstrating potential for improving accuracy and safety in surgery.
12	Song E-K, Seon J-K, Park S-J, Jung WB, Park H-W, Lee GW. Simultaneous bilateral total knee arthroplasty with robotic and conventional techniques: a prospective, randomized study. Knee Surg Sports Traumatol Arthrosc 2011;19:1069–76. https://doi.org/10.1007/s00167-011-1400-9.	• Robotic-assisted TKA resulted in better alignment accuracy and nonsignificantly better postoperative knee scores, range of motions, and bleeding times. • Robotic-assisted TKA needed longer operation times and longer incisions.
13	Lang JE, Mannava S, Floyd AJ, Goddard MS, Smith BP, Mofidi A, et al. Robotic systems in orthopaedic surgery. J Bone Joint Surg Br 2011;93:1296–9. https://doi.org/10.1302/0301-620X.93B10.27418.	• Robot-assisted UKA procedures demonstrate short-term improvements in clinical and radiological outcomes, which have increased the popularity of this technique.
14	Park SE, Lee CT. Comparison of robotic-assisted and conventional manual implantation of a primary total knee arthroplasty. J Arthroplasty 2007;22:1054–9. https://doi.org/10.1016/j.arth.2007.05.036.	• Advantages of robotic-assisted technology for primary TKA include pre-operative planning, accuracy of intraoperative procedure, and post-operative follow-up. • A disadvantage of robotic-assisted technology for primary TKA was the high complication rate in the early stage.
15	Kayani B, Konan S, Tahmassebi J, Pietrzak JRT, Haddad FS. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: a prospective cohort study. Bone Joint J 2018;100-B:930–7. https://doi.org/10.1302/0301-620X.100B7.BJJ-2017-1449.R1.	• Robotic-arm assisted TKA demonstrated reduced postoperative pain, improved early functional recovery, and reduced median time to hospital discharge compared to conventional jig-based techniques.
16	Liow MHL, Xia Z, Wong MK, Tay KJ, Yeo SJ, Chin PL. Robot-assisted total knee arthroplasty accurately restores the joint line and mechanical axis. A prospective randomised study. J Arthroplasty 2014;29:2373–7. https://doi.org/10.1016/j.arth.2013.12.010.	• Robot-assisted TKA demonstrates reduced mechanical axis alignment and joint-line deviation outliers compared to conventional techniques. • Robotic-assisted TKA demonstrates similar short-term clinical outcomes compared to conventional techniques.
17	Pearle AD, O'Loughlin PF, Kendoff DO. Robot-assisted unicompartmental knee arthroplasty. J Arthroplasty 2010;25:230–7. https://doi.org/10.1016/j.arth.2008.09.024.	• Robotic-assisted UKA can decrease implant positioning and limb alignment outliers. • There is an absence of extensive studies on clinical outcomes and long-term results.
18	Bellemans J, Vandenneucker H, Vanlauwe J. Robot-assisted total knee arthroplasty. Clin Orthop Relat Res 2007;464:111–6. https://doi.org/10.1097/BLO.0b013e318126c0c0.	• Robotic-assisted TKA demonstrates excellent implant positioning and alignment. • Robotic-assisted TKA required excessive operating times, technical complexity, and high operational costs.
19	Schulz AP, Seide K, Queitsch C, von Haugwitz A, Meiners J, Kienast B, et al. Results of total hip replacement using the Robodoc surgical assistant	• Use of the Orthodoc/Robodoc system with robotic-assisted THA resulted in equal results compared to manual technique.

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Table 7 (*continued*)

Rank	Article citation	Summary
	system: clinical outcome and evaluation of complications for 97 procedures. Int J Med Robot 2007;3:301−6. https://doi.org/10.1002/rcs.161.	• Robotic-assisted THA resulted in a high number of technical complications directly or indirectly related to the robot.
20	Jakopec M, Rodriguez y Baena F, Harris SJ, Gomes P, Cobb J, Davies BL. The hands-on orthopaedic robot "acrobot": Early clinical trials of total knee replacement surgery. IEEE Transactions on Robotics and Automation 2003;19:902−11. https://doi.org/10.1109/TRA.2003.817510.	• The Acrobot system is suggested to be a safe and effective tool for TKA.
21	Dunbar NJ, Roche MW, Park BH, Branch SH, Conditt MA, Banks SA. Accuracy of dynamic tactile-guided unicompartmental knee arthroplasty. J Arthroplasty 2012;27:803-808.e1. https://doi.org/10.1016/j.arth.2011.09.021.	• Tactile-robotic assisted UKA demonstrated comparable implant placement errors with rigid stereotactic fixation techniques.
22	Sugano N. Computer-assisted orthopaedic surgery and robotic surgery in total hip arthroplasty. Clin Orthop Surg 2013;5:1−9. https://doi.org/10.4055/cios.2013.5.1.1.	• CT-based navigation is more accurate than imageless navigation and fluoro-navigation, but each technique has unique strengths and benefits. • Cup-alignment with navigation is more precise than that of conventional mechanical instruments and is useful for optimizing limb length, range of motion, and stability.
23	Pearle AD, van der List JP, Lee L, Coon TM, Borus TA, Roche MW. Survivorship and patient satisfaction of robotic-assisted medial unicompartmental knee arthroplasty at a minimum 2-year follow-up. Knee 2017;24:419−28. https://doi.org/10.1016/j.knee.2016.12.001.	• Robotic-assisted UKA resulted in high short-term survivorship and satisfaction rate but longer-term studies are needed.
24	Kayani B, Konan S, Huq SS, Tahmassebi J, Haddad FS. Robotic-arm assisted total knee arthroplasty has a learning curve of seven cases for integration into the surgical workflow but no learning curve effect for accuracy of implant positioning. Knee Surg Sports Traumatol Arthrosc 2019;27:1132−41. https://doi.org/10.1007/s00167-018-5138-5.	• Implementation of robotic-arm assisted TKA led to increased operative times and surgical team anxiety during initial cases. • Robotic-arm assisted TKA improved accuracy of implant positioning and limb alignment when compared to conventional techniques.
25	Blyth MJG, Anthony I, Rowe P, Banger MS, MacLean A, Jones B. Robotic arm-assisted versus conventional unicompartmental knee arthroplasty: Exploratory secondary analysis of a randomised controlled trial. Bone Joint Res 2017;6:631−9. https://doi.org/10.1302/2046-3758.611.BJR-2017-0060.R1.	• Robotic arm-assisted UKA resulted in improved early pain scores and early function scores but no difference at 1 year postoperatively.
26	Marchand RC, Sodhi N, Khlopas A, Sultan AA, Harwin SF, Malkani AL, et al. Patient Satisfaction Outcomes after Robotic Arm-Assisted Total Knee Arthroplasty: A Short-Term Evaluation. J Knee Surg 2017;30:849−53. https://doi.org/10.1055/s-0037-1607450.	• Robotic arm-assisted TKA results in improved short term outcomes in pain, physical function, and total satisfaction scores compared to conventional techniques.
27	Moschetti WE, Konopka JF, Rubash HE, Genuario JW. Can Robot-Assisted Unicompartmental Knee Arthroplasty Be Cost-Effective? A Markov Decision Analysis. J Arthroplasty 2016;31:759−65. https://doi.org/10.1016/j.arth.2015.10.018.	• Robot-assisted UKA is shown to be cost-effective compared with conventional techniques when case volume exceeds 94 cases per year. • Robot-assisted UKA is not cost-effective at low-volume or medium-volume arthroplasty centers.
28	Nakamura N, Sugano N, Nishii T, Kakimoto A, Miki H. A comparison between robotic-assisted and manual implantation of cementless total hip arthroplasty. Clin Orthop Relat Res 2010;468:1072−81. https://doi.org/10.1007/s11999-009-1158-2.	• Robotic-assisted THA resulted in more precise implant positioning and less variance in limb-length inequality and stress shielding of the proximal femur at 5 years postoperatively compared to conventional techniques.
29	Batailler C, White N, Ranaldi FM, Neyret P, Servien E, Lustig S. Improved implant position and lower revision rate with robotic-assisted unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2019;27:1232−40. https://doi.org/10.1007/s00167-018-5081-5.	• Robotic-assisted UKA resulted in a lower rate of limb alignment outliers and revision rate compared to conventional techniques.
30	Plate JF, Mofidi A, Mannava S, Smith BP, Lang JE, Poehling GG, et al. Achieving accurate ligament balancing using robotic-assisted unicompartmental knee arthroplasty. Adv Orthop 2013;2013:837167. https://doi.org/10.1155/2013/837167.	• Robotic-assisted UKA results in accurate and precise reproduction of a surgical balance plan to help restore natural knee kinematics
31	Sodhi N, Khlopas A, Piuzzi NS, Sultan AA, Marchand RC, Malkani AL, et al. The Learning Curve Associated with Robotic Total Knee Arthroplasty. J Knee Surg 2018;31:17−21.	• Initial robotic TKA cases resulted in longer operating times compared to manual cases. • After a learning curve, robotic TKA cases had similar operating times to manual cases.
32	Kayani B, Konan S, Pietrzak JRT, Haddad FS. Iatrogenic Bone and Soft Tissue Trauma in Robotic-Arm Assisted Total Knee Arthroplasty Compared With Conventional Jig-Based Total Knee Arthroplasty: A Prospective Cohort Study and Validation of a New Classification System. J Arthroplasty 2018;33:2496−501. https://doi.org/10.1016/j.arth.2018.03.042.	• Robotic-arm assisted TKA resulted in reduced bone and periarticular soft tissue injury compared to conventional techniques. • The proposed MASTI classification system can facilitate further research relating soft tissue injury to long-term clinical and functional outcomes in TKA.
33	Liow MHL, Goh GS-H, Wong MK, Chin PL, Tay DK-J, Yeo S-J. Robotic-assisted total knee arthroplasty may lead to improvement in quality-of-life measures: a 2-year follow-up of a prospective randomized trial. Knee Surg Sports Traumatol Arthrosc 2017;25:2942−51. https://doi.org/10.1007/s00167-016-4076-3.	• Robotic-assisted TKA resulted in a higher rate of complications compared to conventional techniques. • Robotic-assisted TKA resulted in subtle improvements in patient quality of life measures compared to conventional techniques.
34	Kayani B, Konan S, Pietrzak JRT, Huq SS, Tahmassebi J, Haddad FS. The learning curve associated with robotic-arm assisted unicompartmental knee arthroplasty: a prospective cohort study. Bone Joint J 2018;100-B:1033−42. https://doi.org/10.1302/0301-620X.100B8.BJJ-2018-0040.R1.	• Robotic-arm assisted UKA seemingly had a learning curve of 6 cases to normalize operating time and surgical team confidence levels but did not have a learning curve for implant positioning accuracy.
35	Kayani B, Konan S, Tahmassebi J, Rowan FE, Haddad FS. An assessment of early functional rehabilitation and hospital discharge in conventional versus robotic-arm assisted unicompartmental knee arthroplasty: a prospective cohort study. Bone Joint J 2019;101-B:24−33. https://doi.org/10.1302/0301-620X.101B1.BJJ-2018-0564.R2.	• Robotic-arm assisted UKA resulted in decreased postoperative pain and analgesia requirements, improved early functional outcomes, and shorter time to hospital discharge compared to conventional techniques.
36	Domb BG, Redmond JM, Louis SS, Alden KJ, Daley RJ, LaReau JM, et al. Accuracy of Component Positioning in 1980 Total Hip Arthroplasties: A	• Robotic-guided THA was found to be more consistent and accurate in placing the acetabular component within Callanan's safe zone compared to conventional techniques.

Table 7 (*continued*)

Rank	Article citation	Summary
	Comparative Analysis by Surgical Technique and Mode of Guidance. J Arthroplasty 2015;30:2208–18. https://doi.org/10.1016/j.arth.2015.06.059.	• Robotic-guided THA was found to have no significant difference in frequency of patients with leg length discrepancy or global offset difference.
37	Gilmour A, MacLean AD, Rowe PJ, Banger MS, Donnelly I, Jones BG, et al. Robotic-Arm-Assisted vs Conventional Unicompartmental Knee Arthroplasty. The 2-Year Clinical Outcomes of a Randomized Controlled Trial. J Arthroplasty 2018;33:S109–15. https://doi.org/10.1016/j.arth.2018.02.050.	• Robotic-arm-assisted UKA resulted in similar outcomes overall to conventional techniques. • Robotic-arm-assisted UKA may yield improved outcomes for more active patients.
38	Kazanzides P, Mittelstadt BD, Musits BL, Bargar WL, Zuhars JF, Williamson B, et al. An integrated system for cementless hip replacement. IEEE Engineering in Medicine and Biology Magazine 1995;14:307–13. https://doi.org/10.1109/51.391772.	• The Robodoc system is suggested to be a safe and effective tool for performing cementless hip replacement. • Initial results indicate the Robodoc system may reduce technique-related failures and intraoperative complications.
39	Herry Y, Batailler C, Lording T, Servien E, Neyret P, Lustig S. Improved joint-line restitution in unicompartmental knee arthroplasty using a robotic-assisted surgical technique. Int Orthop 2017;41:2265–71. https://doi.org/10.1007/s00264-017-3633-9.	• Robotic-assisted UKA can improve restitution of joint-line height.
40	Nishihara S, Sugano N, Nishii T, Miki H, Nakamura N, Yoshikawa H. Comparison between hand rasping and robotic milling for stem implantation in cementless total hip arthroplasty. J Arthroplasty 2006;21:957–66. https://doi.org/10.1016/j.arth.2006.01.001.	• The robotic milling group resulted in superior Merle D'Aubigne hip score, no intraoperative femoral fractures, and a superior implant fit when compared to hand rasping for stem implantation.
41	Decking J, Theis C, Achenbach T, Roth E, Nafe B, Eckardt A. Robotic total knee arthroplasty: the accuracy of CT-based component placement. Acta Orthop Scand 2004;75:573–9. https://doi.org/10.1080/00016470410001448.	• Robotic TKA is associated with high accuracy of component placement. • Robotic TKA requires further development to integrate soft-tissue balancing and optimize the procedure.
42	Yang HY, Seon JK, Shin YJ, Lim HA, Song EK. Robotic Total Knee Arthroplasty with a Cruciate-Retaining Implant: A 10-Year Follow-up Study. Clin Orthop Surg 2017;9:169–76. https://doi.org/10.4055/cios.2017.9.2.169.	• Robotic TKA using a cruciate-retaining implant resulted in similar clinical outcomes and long-term survival rates compared to conventional techniques.
43	Ilgen RL, Bukowski BR, Abiola R, Anderson P, Chughtai M, Khlopas A, et al. Robotic-Assisted Total Hip Arthroplasty: Outcomes at Minimum Two-Year Follow-Up. Surg Technol Int 2017;30:365–72.	• Robotic-assisted THA resulted in improved acetabular component accuracy and reduced dislocation rates when compared to conventional techniques.
44	Plate JF, Augart MA, Seyler TM, Bracey DN, Hoggard A, Akbar M, et al. Obesity has no effect on outcomes following unicompartmental knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2017;25:645–51. https://doi.org/10.1007/s00167-015-3597-5.	• BMI may not influence clinical outcomes and readmission rates of robotic-assisted UKA. • Classic contraindication of BMI >30 kg/m^2 may not be applicable in robotic-assisted UKA.
45	Swank ML, Alkire M, Conditt M, Lonner JH. Technology and cost-effectiveness in knee arthroplasty: computer navigation and robotics. Am J Orthop (Belle Mead NJ) 2009;38:32–6.	• The relatively expensive capital equipment cost of robotic technology for UKA can be regained within a 2-year period. • The positive benefits of robotic-assisted UKA can improve cost-effectiveness of surgery for patients.
46	Hansen DC, Kusuma SK, Palmer RM, Harris KB. Robotic guidance does not improve component position or short-term outcome in medial unicompartmental knee arthroplasty. J Arthroplasty 2014;29:1784–9. https://doi.org/10.1016/j.arth.2014.04.012.	• Robotic-assisted UKA resulted in similar clinical and radiographic outcomes when compared to conventional techniques. • Robotic-assisted UKA resulted in a greater operating time than conventional techniques.
47	Kayani B, Konan S, Ayuob A, Onochie E, Al-Jabri T, Haddad FS. Robotic technology in total knee arthroplasty: a systematic review. EFORT Open Rev 2019;4:611–7. https://doi.org/10.1302/2058-5241.4.190022.	• Robotic TKA is associated with decreased postoperative pain, enhanced early functional rehabilitation, and decreased time to hospital discharge compared to conventional techniques. • Robotic TKA has been shown to have similar medium and long-term functional outcomes compared to conventional techniques.
48	Kleeblad LJ, Borus TA, Coon TM, Dounchis J, Nguyen JT, Pearle AD. Midterm Survivorship and Patient Satisfaction of Robotic-Arm-Assisted Medial Unicompartmental Knee Arthroplasty: A Multicenter Study. J Arthroplasty 2018;33:1719–26. https://doi.org/10.1016/j.arth.2018.01.036.	• Robotic-arm-assisted medial UKA demonstrates high survivorship and satisfaction at midterm follow-up. • Early fixation failure is identified as the primary cause for revision with cemented implants in robotic-arm-assisted medial UKA.
49	Kamara E, Robinson J, Bas MA, Rodriguez JA, Hepinstall MS. Adoption of Robotic vs Fluoroscopic Guidance in Total Hip Arthroplasty: Is Acetabular Positioning Improved in the Learning Curve? J Arthroplasty 2017;32:125–30. https://doi.org/10.1016/j.arth.2016.06.039.	• Robotic THA demonstrates significant and immediate improvement in the precision of acetabular component positioning during the learning curve. • Fluoroscopy guidance in THA is associated with a learning curve before precision improves significantly.
50	Nodzo SR, Chang C-C, Carroll KM, Barlow BT, Banks SA, Padgett DE, et al. Intraoperative placement of total hip arthroplasty components with robotic-arm assisted technology correlates with postoperative implant position: a CT-based study. Bone Joint J 2018;100-B:1303–9. https://doi.org/10.1302/0301-620X.100B10-BJJ-2018-0201.R1.	• Results of robotic-assisted THA in the operating theatre accurately correlated with postoperative component position assessed independently using CT based 3D modeling.
51	Chun YS, Kim KI, Cho YJ, Kim YH, Yoo MC, Rhyu KH. Causes and patterns of aborting a robot-assisted arthroplasty. J Arthroplasty 2011;26:621–5. https://doi.org/10.1016/j.arth.2010.05.017.	• Most of the 22 aborted robot-assisted arthroplasty cases involved TKA and were caused by errors during the milling procedure or interactive factors, highlighting the need for effective decision-making by surgeons.
52	Kim Y-H, Yoon S-H, Park J-W. Does Robotic-assisted TKA Result in Better Outcome Scores or Long-Term Survivorship Than Conventional TKA? A Randomized, Controlled Trial. Clin Orthop Relat Res 2020;478:266–75. https://doi.org/10.1097/CORR.0000000000000916.	• No significant differences were found between robotic-assisted TKA and conventional TKA in terms of functional outcomes, aseptic loosening, overall survivorship, and complications over a minimum follow-up of 10 years.
53	Redmond JM, Gupta A, Hammarstedt JE, Petrakos AE, Finch NA, Domb BG. The learning curve associated with robotic-assisted total hip arthroplasty. J Arthroplasty 2015;30:50–4. https://doi.org/10.1016/j.arth.2014.08.003.	• A study was conducted on the first 105 robotic-assisted THAs performed by a single surgeon, which showed a decreased risk of acetabular component malpositioning and decreased operative time with increased surgical experience.
54	Roche M, O'Loughlin PF, Kendoff D, Musahl V, Pearle AD. Robotic arm-assisted unicompartmental knee arthroplasty: preoperative planning and surgical technique. Am J Orthop (Belle Mead NJ) 2009;38:10–5.	• The recently developed CAS/robotic system, which is semiactive and allows the surgeon to retain control while benefiting from robotic guidance, has the potential to improve the results of UKA by providing precise execution of a patient-specific surgical plan.

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Table 7 (*continued*)

Rank	Article citation	Summary
55	Marchand RC, Sodhi N, Khlopas A, Sultan AA, Higuera CA, Stearns KL, et al. Coronal Correction for Severe Deformity Using Robotic-Assisted Total Knee Arthroplasty. J Knee Surg 2018;31:2–5. https://doi.org/10.1055/s-0037-1608840.	• The robotic-assisted device for TKA corrected knees within a few degrees of neutral and none of them were overcorrected. • Future studies are needed to evaluate the clinical outcomes of achieving alignment goals with this device, but the results demonstrate its potential for helping surgeons achieve desired neutral alignment in TKA.
56	Jeon S-W, Kim K-I, Song SJ. Robot-Assisted Total Knee Arthroplasty Does Not Improve Long-Term Clinical and Radiologic Outcomes. J Arthroplasty 2019;34:1656–61. https://doi.org/10.1016/j.arth.2019.04.007.	• Conventional TKA has similar long-term clinical and radiologic outcomes as robot-assisted TKA. • Robot-assisted TKA does not offer any significant advantage in improving long-term clinical or radiologic outcomes over conventional TKA.
57	Cho K-J, Seon J-K, Jang W-Y, Park C-G, Song E-K. Robotic versus conventional primary total knee arthroplasty: clinical and radiological long-term results with a minimum follow-up of 10 years. Int Orthop 2019;43:1345–54. https://doi.org/10.1007/s00264-018-4231-1.	• The study found similar long-term clinical outcomes and excellent survival rates for both robotic and conventional TKA. • Robotic TKA demonstrated better radiological accuracy and consistency with fewer outliers compared to conventional TKA, suggesting its potential for improved implant survival rate.
58	Dretakis K, Igoumenou VG. Outcomes of robotic-arm-assisted medial unicompartmental knee arthroplasty: minimum 3-year follow-up. Eur J Orthop Surg Traumatol 2019;29:1305–11. https://doi.org/10.1007/s00590-019-02424-4.	• Robotic-arm-assisted UKA can improve range of motion and coronal plane alignment with accurate implant positioning, leading to high overall satisfaction rates and excellent clinical outcomes.
59	Börner M, Bauer A, Lahmer A. Computer-guided robot-assisted hip endoprosthesis. Orthopade 1997;26:251–7. https://doi.org/10.1007/s001320050092.	• The use of Robodoc in robot-assisted surgery has resulted in successful implementation of preoperative plans in all 465 patients, with no implant subsidence observed in follow-up X-ray studies despite immediate full-weight bearing.
60	Boylan M, Suchman K, Vigdorchik J, Slover J, Bosco J. Technology-Assisted Hip and Knee Arthroplasties: An Analysis of Utilization Trends. J Arthroplasty 2018;33:1019–23. https://doi.org/10.1016/j.arth.2017.11.033.	• Orthopaedic surgeons are increasingly using technology assistance for hip and knee arthroplasties. • The adoption of technology assistance is not uniform.
61	Liow MHL, Chin PL, Tay KJD, Chia SL, Lo NN, Yeo SJ. Early experiences with robot-assisted total knee arthroplasty using the DigiMatch ROBODOC surgical system. Singapore Med J 2014;55:529–34. https://doi.org/10.11622/smedj.2014136.	• Robotics can help achieve precise postoperative alignment in TKA surgery. • Robotics, with bone movement monitors and navigation systems, can reduce errors but the surgeon's role in planning and execution remains crucial.
62	Lonner JH. Indications for unicompartmental knee arthroplasty and rationale for robotic arm-assisted technology. Am J Orthop (Belle Mead NJ) 2009;38:3–6.	• UKA is effective for treating focal arthritis with proper selection criteria and bone preparation. • Robotics has improved component alignment and precision in UKA, even with minimally invasive soft-tissue approaches.
63	Pearle AD, Kendoff D, Stueber V, Musahl V, Repicci JA. Perioperative management of unicompartmental knee arthroplasty using the MAKO robotic arm system (MAKOplasty). Am J Orthop (Belle Mead NJ) 2009;38:16–9.	• UKA is a popular treatment for unicompartmental knee arthritis with indications including mechanical axis of less than 10 degrees varus and less than 5 degrees valgus, intact ACL, and absence of femorotibial subluxation. • UKA failures are not common and newly developed robotic technology can improve surgical precision.
64	Thienpont E, Fennema P, Price A. Can technology improve alignment during knee arthroplasty. Knee 2013;20 Suppl 1:S21-28. https://doi.org/10.1016/S0968-0160(13)70005-X.	• Computer-assisted navigation improves alignment in TKA compared to conventional instrumentation. • Patient-matched instrumentation and robot-assisted implantation have not reliably demonstrated alignment benefits and further studies are required.
65	Kanawade V, Dorr LD, Banks SA, Zhang Z, Wan Z. Precision of robotic guided instrumentation for acetabular component positioning. J Arthroplasty 2015;30:392–7. https://doi.org/10.1016/j.arth.2014.10.021.	• Robotic computerized instrumentation achieves precise cup inclination and anteversion in 88% and 84% of cases, respectively, and COR in 81.5% of cases in total hip arthroplasty. Outliers of 5° were not observed intraoperatively.
66	Banerjee S, Cherian JJ, Elmallah RK, Jauregui JJ, Pierce TP, Mont MA. Robotic-assisted knee arthroplasty. Expert Rev Med Devices 2015;12:727–35. https://doi.org/10.1586/17434440.2015.1086264.	• Semiactive haptic robotic systems for TKA offer benefits including improvements in radiographic outcomes and lower extremity alignment, but more studies on functional outcomes and cost-benefit analysis are needed before widespread adoption.
67	Hananouchi T, Sugano N, Nishii T, Nakamura N, Miki H, Kakimoto A, et al. Effect of robotic milling on periprosthetic bone remodeling. J Orthop Res 2007;25:1062–9. https://doi.org/10.1002/jor.20376.	• Robotic milling in cementless THA using the ROBODOC system leads to significantly less bone loss in the proximal periprosthetic areas and facilitates proximal load transfer around the femoral component compared to conventional rasping.
68	Marchand RC, Sodhi N, Anis HK, Ehiorobo J, Newman JM, Taylor K, et al. One-Year Patient Outcomes for Robotic-Arm-Assisted versus Manual Total Knee Arthroplasty. J Knee Surg 2019;32:1063–8. https://doi.org/10.1055/s-0039-1683977.	• Study compares patient-reported outcomes between manual and robotic arm-assisted TKA, finding that the robotic arm-assisted technique leads to significantly improved total and physical function scores compared to manual TKA. • Pain scores also trended lower for the robotic arm-assisted cohort.
69	Cool CL, Jacofsky DJ, Seeger KA, Sodhi N, Mont MA. A 90-day episode-of-care cost analysis of robotic-arm assisted total knee arthroplasty. J Comp Eff Res 2019;8:327–36. https://doi.org/10.2217/cer-2018-0136.	• Robotic arm-assisted TKA had a lower 90-day estimated overall cost compared to manual TKA. • The savings were due to fewer readmissions and economically beneficial discharge destinations.
70	Khlopas A, Sodhi N, Sultan AA, Chughtai M, Molloy RM, Mont MA. Robotic Arm-Assisted Total Knee Arthroplasty. J Arthroplasty 2018;33:2002–6. https://doi.org/10.1016/j.arth.2018.01.060.	• Robotic arm-assisted TKA has potential advantages, but most studies have reported short-term outcomes. • Longer term studies are needed to determine if RATKA provides higher patient satisfaction and other clinical outcomes.
71	Mofidi A, Plate JF, Lu B, Conditt MA, Lang JE, Poehling GG, et al. Assessment of accuracy of robotically assisted unicompartmental arthroplasty. Knee Surg Sports Traumatol Arthrosc 2014;22:1918–25. https://doi.org/10.1007/s00167-014-2969-6.	• Robotic-assisted medial UKA leads to precise prosthesis positioning. • Inaccuracy may be due to inadequate cementing methods.

Table 7 (*continued*)

Rank	Article citation	Summary
72	Davies BL, Rodriguez y Baena FM, Barrett ARW, Gomes MPSF, Harris SJ, Jakopec M, et al. Robotic control in knee joint replacement surgery. Proc Inst Mech Eng H 2007;221:71–80. https://doi.org/10.1243/09544119JEIM250.	• The history of robotic systems in knee arthroplasty is discussed. • The use of cost-effective, hands-on robotic systems is compared to autonomous robots, with a call for clear justification and improved benefits.
73	Canetti R, Batailler C, Bankhead C, Neyret P, Servien E, Lustig S. Faster return to sport after robotic-assisted lateral unicompartmental knee arthroplasty: a comparative study. Arch Orthop Trauma Surg 2018;138:1765–71. https://doi.org/10.1007/s00402-018-3042-6.	• Robotic-assisted lateral UKA leads to quicker return to presymptomatic sports levels compared to conventional surgery. • High return to sports rate observed in both groups; long-term study needed to assess prosthesis wear in this active population.
74	Antonios JK, Korber S, Sivasundaram L, Mayfield C, Kang HP, Oakes DA, et al. Trends in computer navigation and robotic assistance for total knee arthroplasty in the United States: an analysis of patient and hospital factors. Arthroplasty Today 2019;5:88–95. https://doi.org/10.1016/j.artd.2019.01.002.	• Computer navigation and robot-assisted TKA usage rose to 7.0% of all TKAs in the US in 2014 • Their use was associated with higher hospital charges and varied regionally.
75	van der List JP, Chawla H, Joskowicz L, Pearle AD. Current state of computer navigation and robotics in unicompartmental and total knee arthroplasty: a systematic review with meta-analysis. Knee Surg Sports Traumatol Arthrosc 2016;24:3482–95. https://doi.org/10.1007/s00167-016-4305-9.	• Computer navigation and robotic-assisted systems can improve surgical outcomes for knee arthroplasty by controlling lower leg alignment, component positioning, and soft tissue balancing. • Computer navigation with soft tissue balancing has been shown to have significantly better outcomes compared to conventional TKA.
76	Rodriguez F, Harris S, Jakopec M, Barrett A, Gomes P, Henckel J, et al. Robotic clinical trials of uni-condylar arthroplasty. The International Journal of Medical Robotics and Computer Assisted Surgery 2005;1:20–8. https://doi.org/10.1002/rcs.52.	• A randomized clinical trial for unicondylar arthroplasty using robotic surgery showed significant improvement in accuracy compared to conventional surgery. • The Acrobot hands-on robotic system uses preoperative planning with 3D CT models and CAD models of prostheses to plan leg alignment, position prostheses, and generate regions for cuts.
77	Bukowski BR, Anderson P, Khlopas A, Chughtai M, Mont MA, Illgen RL. Improved Functional Outcomes with Robotic Compared with Manual Total Hip Arthroplasty. Surg Technol Int 2016;29:303–8.	• Robotic THA results in better functional outcomes compared to traditional THA at 1-year follow-up. • Further multicenter studies are needed to determine if these advantages are sustained over longer periods.
78	Clement ND, Deehan DJ, Patton JT. Robot-assisted unicompartmental knee arthroplasty for patients with isolated medial compartment osteoarthritis is cost-effective: a Markov decision analysis. Bone Joint J 2019;101-B:1063–70. https://doi.org/10.1302/0301-620X.101B9.BJJ-2018-1658.R1.	• Robotic-assisted UKA is a cheaper option for patients with isolated medial compartment osteoarthritis of the knee compared to manual TKA and UKA. • The cost per QALY of robotic-assisted UKA decreases with shorter hospital stays and higher case volumes, compared to TKA and UKA.
79	Robinson PG, Clement ND, Hamilton D, Blyth MJG, Haddad FS, Patton JT. A systematic review of robotic-assisted unicompartmental knee arthroplasty: prosthesis design and type should be reported. Bone Joint J 2019;101-B:838–47. https://doi.org/10.1302/0301-620X.101B7.BJJ-2018-1317.R1.	• Choice of implant in robotic-assisted UKA is underreported in the literature, but essential for assessing survivorship. • Robotic-assisted UKA improves implant positioning accuracy and reproducibility and may lead to better functional outcomes, but the effect on mid- to long-term implant survival is unclear.
80	Lonner JH, Fillingham YA. Pros and Cons: A Balanced View of Robotics in Knee Arthroplasty. J Arthroplasty 2018;33:2007–13. https://doi.org/10.1016/j.arth.2018.03.056.	• Robotic technology in TKA improves bone preparation and component alignment, reduces outliers, and increases the percentage of components aligned within 2° or 3° of the target. • However, the improved alignment may not necessarily improve function and implant durability.
81	Bargar WL, Parise CA, Hankins A, Marlen NA, Campanelli V, Netravali NA. Fourteen Year Follow-Up of Randomized Clinical Trials of Active Robotic-Assisted Total Hip Arthroplasty. J Arthroplasty 2018;33:810–4. https://doi.org/10.1016/j.arth.2017.09.066.	• Active robot system improves implant fit and alignment • Long-term study shows no stem loosening failures and small clinical outcome improvements in the robot group.
82	Netravali NA, Shen F, Park Y, Bargar WL. A perspective on robotic assistance for knee arthroplasty. Adv Orthop 2013;2013:970703. https://doi.org/10.1155/2013/970703.	• Knee arthroplasty is used to treat degenerative joint disease of the knee. • Robotic-assisted surgery can lead to improved surgical technique and clinical outcomes for knee replacement patients.
83	Siebel T, Käfer W. Clinical outcome following robotic assisted versus conventional total hip arthroplasty: a controlled and prospective study of seventy-one patients. Z Orthop Ihre Grenzgeb 2005;143:391–8. https://doi.org/10.1055/s-2005-836776.	• Robotic assisted THA may cause functional impairment. • Careful consideration is necessary before performing this procedure.
84	Bach CM, Winter P, Nogler M, Göbel G, Wimmer C, Ogon M. No functional impairment after Robodoc total hip arthroplasty. Acta Orthopaedica Scandinavica 2002;73:386–91. https://doi.org/10.1080/00016470216316.	• The reduction in hip abduction did not differ significantly between patients undergoing robotic or conventional THA, indicating that the robotic procedure did not impair hip abductor function more than the conventional method.
85	Sultan AA, Piuzzi N, Khlopas A, Chughtai M, Sodhi N, Mont MA. Utilization of robotic-arm assisted total knee arthroplasty for soft tissue protection. Expert Rev Med Devices 2017;14:925–7. https://doi.org/10.1080/17434440.2017.1392237.	• Robotic-arm assisted TKA has shown promising results in implant positioning and mechanical accuracy, as well as potentially reducing soft tissue injuries caused by human technical errors during standard manual resections. • Recent studies have shown comparable or superior clinical outcomes and soft tissue protection in short- and mid-term follow-up compared to manual TKA.
86	Elson L, Dounchis J, Illgen R, Marchand RC, Padgett DE, Bragdon CR, et al. Precision of acetabular cup placement in robotic integrated total hip arthroplasty. Hip Int 2015;25:531–6. https://doi.org/10.5301/hipint.5000289.	• Robotic-arm cup placement was accurate within ± 4 degrees of planned position in 95% of cases. • Intraoperative robotic assistance improved the precision of preparation and position of the acetabular cup during THA.
87	Marchand RC, Sodhi N, Bhowmik-Stoker M, Scholl L, Condrey C, Khlopas A, et al. Does the Robotic Arm and Preoperative CT Planning Help with 3D Intraoperative Total Knee Arthroplasty Planning? J Knee Surg 2019;32:742–9. https://doi.org/10.1055/s-0038-1668122.	• Robotic-arm assisted TKA provided significant intraoperative assistance, with most patients achieving accurate flexion and extension gaps and predicted implant sizes, and no significant intraoperative complications or related readmissions reported.

(*continued on next page*)

Table 7 (*continued*)

Rank	Article citation	Summary
88	Kayani B, Konan S, Thakrar RR, Huq SS, Haddad FS. Assuring the long-term total joint arthroplasty: a triad of variables. Bone Joint J 2019;101-B:11–8. https://doi.org/10.1302/0301-620X.101B1.BJJ-2018-0377.R1.	• Robotic-arm assisted THA improves accuracy in restoring the native centre of rotation and precise acetabular component positioning compared to manual THA. • It also results in better preservation of the combined offset and positions components within safe zones of inclination and anteversion.
89	Chen X, Xiong J, Wang P, Zhu S, Qi W, Peng H, et al. Robotic-assisted compared with conventional total hip arthroplasty: systematic review and meta-analysis. Postgrad Med J 2018;94:335–41. https://doi.org/10.1136/postgradmedj-2017-135352.	• Robotic-assisted THA is better than conventional THA in terms of component positioning and intraoperative complication rates, according to this meta-analysis.
90	Ren Y, Cao S, Wu J, Weng X, Feng B. Efficacy and reliability of active robotic-assisted total knee arthroplasty compared with conventional total knee arthroplasty: a systematic review and meta-analysis. Postgrad Med J 2019;95:125–33. https://doi.org/10.1136/postgradmedj-2018-136190.	• Active robotic-assisted TKA surgeries lead to improved mechanical alignment and prosthesis implantation compared to conventional surgery.
91	Tsai T-Y, Dimitriou D, Li J-S, Kwon Y-M. Does haptic robot-assisted total hip arthroplasty better restore native acetabular and femoral anatomy? Int J Med Robot 2016;12:288–95. https://doi.org/10.1002/rcs.1663.	• Robot-assisted THA is more precise than free-hand THA in restoring the native hip geometry. • However, neither method fully restores the native hip geometry.
92	MacCallum KP, Danoff JR, Geller JA. Tibial baseplate positioning in robotic-assisted and conventional unicompartmental knee arthroplasty. Eur J Orthop Surg Traumatol 2016;26:93–8. https://doi.org/10.1007/s00590-015-1708-0.	• Robotic-arm-assisted UKA demonstrated more accurate coronal baseplate positioning compared to conventional UKA. • However, there was no significant difference in the percentage of implants within a predetermined safe zone between the 2 groups.
93	Gupta A, Redmond JM, Hammarstedt JE, Petrakos AE, Vemula SP, Domb BG. Does Robotic-Assisted Computer Navigation Affect Acetabular Cup Positioning in Total Hip Arthroplasty in the Obese Patient? A Comparison Study. J Arthroplasty 2015;30:2204–7. https://doi.org/10.1016/j.arth.2015.06.062.	• The study found that robotic-assisted computer navigation can provide accurate and reproducible placement of the acetabular cup within safe zones for inclination and version in obese patients undergoing total hip arthroplasty. • The accuracy of acetabular cup inclination and version did not differ significantly between obese patients with different BMI categories (<30, 30-35, and >35).
94	St Mart J-P, de Steiger RN, Cuthbert A, Donnelly W. The 3-year survivorship of robotically assisted versus non-robotically assisted unicompartmental knee arthroplasty. Bone Joint J 2020;102-B:319–28. https://doi.org/10.1302/0301-620X.102B3.BJJ-2019-0713.R1.	• Mako robotically assisted UKA shows similar short-term survivorship compared to ZUK UKA and better survivorship compared to all other nonrobotic UKA. • Higher rate of early revision for infection in robotically assisted UKA suggests further investigation is necessary.
95	Burger JA, Kleeblad LJ, Laas N, Pearle AD. Mid-term survivorship and patient-reported outcomes of robotic-arm assisted partial knee arthroplasty. Bone Joint J 2020;102-B:108–16. https://doi.org/10.1302/0301-620X.102B1.BJJ-2019-0510.R1.	• Study finds high midterm survivorship, satisfaction levels, and functional outcomes in robotic-arm assisted UKA using metal-backed tibial onlay components. • Favorable results also observed in robotic-arm assisted patellofemoral arthroplasty and bicondylar knee arthroplasty.
96	Sires JD, Craik JD, Wilson CJ. Accuracy of Bone Resection in MAKO Total Knee Robotic-Assisted Surgery. J Knee Surg 2021;34:745–8. https://doi.org/10.1055/s-0039-1700570.	• Use of the MAKO TKA system is associated with high accuracy in achieving preoperatively planned bone resection and final limb coronal alignment.
97	Khlopas A, Sodhi N, Hozack WJ, Chen AF, Mahoney OM, Kinsey T, et al. Patient-Reported Functional and Satisfaction Outcomes after Robotic-Arm-Assisted Total Knee Arthroplasty: Early Results of a Prospective Multicenter Investigation. J Knee Surg 2020;33:685–90. https://doi.org/10.1055/s-0039-1684014.	• Robot assisted TKA led to greater improvements in 9 out of 10 outcome scores at the 3 month postoperative point when compared to manual TKA.
98	Kayani B, Konan S, Ayuob A, Ayyad S, Haddad FS. The current role of robotics in total hip arthroplasty. EFORT Open Rev 2019;4:618–25. https://doi.org/10.1302/2058-5241.4.180088.	• Robotic assisted THA improves accuracy and precision in achieving the planned acetabular cup positioning and centre of hip rotation when compared to manual THA.
99	Karunaratne S, Duan M, Pappas E, Fritsch B, Boyle R, Gupta S, et al. The effectiveness of robotic hip and knee arthroplasty on patient-reported outcomes: A systematic review and meta-analysis. Int Orthop 2019;43:1283–95. https://doi.org/10.1007/s00264-018-4140-3.	• The functional outcomes for patients undergoing both robotic THA and TKA were comparable to conventional THA and TKA. • Improvement in postoperative pain, quality of life and satisfaction with robotic surgery is unclear.
100	Perets I, Walsh JP, Close MR, Mu BH, Yuen LC, Domb BG. Robot-assisted total hip arthroplasty: Clinical outcomes and complication rate. Int J Med Robot 2018;14:e1912. https://doi.org/10.1002/rcs.1912.	• Robotic THA is associated with favorable short-term outcomes and was not found to result in a higher complication rate when compared to manual THA.

be used to stratify the literature and avoid as much ambiguity as possible. Finally, the Web of Knowledge Database that was used for this analysis, while comprehensive, may have excluded certain articles by either search criteria discrepancies or the tabulation of article citations.

Conclusions

Research on robotic arthroplasty is rapidly growing and originates from a wide variety of countries, academic institutions, and with significant industry influence. This article serves as a reference to direct orthopaedic practitioners to the 100 most influential studies in robotic arthroplasty. We hope that these 100 studies and the analysis we provide aid healthcare professionals in efficiently assessing consensus, trends, and needs within the field.

Appendix

The final Boolean search terms used to generate the largest number of results were: "(arthroplasty (OR) joint arthroplasty (OR) joint replacement (OR) knee arthroplasty (OR) knee replacement (OR) hip arthroplasty (OR) hip replacement (OR) shoulder arthroplasty (OR) shoulder replacement (OR) ankle arthroplasty (OR) ankle replacement (OR) joint reconstruction (OR) total knee arthroplasty (OR) total knee replacement (OR) total hip arthroplasty (OR) total hip replacement (OR) total ankle arthroplasty (OR) total ankle replacement (OR) total shoulder arthroplasty (OR) total shoulder replacement (OR) partial knee arthroplasty (OR) unicompartmental knee arthroplasty (OR) partial knee replacement (OR) unicompartmental knee replacement) AND (robotic surgery (OR) robotic technology (OR) robotic systems (OR) robotics (OR) robot-assisted surgery (OR) robot assisted surgery (OR) robotic-arm assisted surgery (OR) robotic arm assisted surgery (OR) robotic (OR) robot)".

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101153.

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