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RESEARCH

Is robotic assistance more eye-catching than computer navigation in joint arthroplasty? A Google trends analysis from the point of public interest

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Abstract

Computer-assisted navigation system (CAS) and robotic assisted surgery (RAS) have been widely used in joint arthroplasty, but few studies focused on public interest. We aimed to evaluate current trend and seasonality of public interest in CAS and RAS arthroplasty over the past 10 years, and forecast the future development. All data related to CAS or RAS arthroplasty from January 2012 to December 2021 were collected through Google Trends. Public interest was described by relative search volume (RSV). Pre-existing trend was evaluated by linear and exponential models. Time series analysis and ARIMA model were utilized to analyze the seasonality and future trend. R software 3.5.0 was for statistics analysis. Public interest in RAS arthroplasty has been continuously increasing ($P < 0.001$) and exponential model ($R^2 = 0.83$, MAE = 7.35, MAPE = 34%, RSME = 9.58) fitted better than linear one ($R^2 = 0.78$, MAE = 8.44, MAPE = 42%, RSME = 10.67). CAS arthroplasty showed a downtrend ($P < 0.01$) with equivalent R^2 (0.04) and accuracy measures (MAE = 3.92, MAPE = 31%, RSME = 4.95). The greatest popularity of RAS was observed in July and October, while the lowest was in March and December. For CAS, a rise of public interest was in May and October, but lower values were observed in January and November. Based on ARIMA models, the popularity of RAS might continuously increase and nearly double in 2030, along with a stability with slight downtrend for CAS. Public interest in RAS arthroplasty has been continuously increasing and seems to maintain this uptrend in the next 10 years, whereas popularity of CAS arthroplasty will likely remain stable.

Keywords Computer assisted navigation · Robotic assisted surgery · Arthroplasty · Public interest · Time series analysis

Introduction

Joint arthroplasty is one of the most commonly applied procedures in orthopedics, prescribed for patients with end-stage osteoarthritis (OA) and various other joint lesions. Due to the globally aging population and continuously growing prevalence of OA, total hip and knee arthroplasty procedures are expected to increase exponentially, by an estimated 70% and 85% respectively in the US alone by the end of 2030 [1]. Conventional joint arthroplasty is a well-accepted and documented, safe and mature procedure. However, this requires extensive surgical training and the numbers of experienced surgeons available often cannot meet the tremendous increasing demand for joint arthroplasty worldwide. Besides, it can still fail due to malalignment associated with implant positioning or soft tissue imbalance during surgery, which may lead to poor clinical function, low implant survival and even revision surgery [2–4]. To improve implant positioning in a personalized manner, new assistive technologies, including computer-assisted navigation system (CAS) and robotic assisted surgery (RAS), have been applied in joint

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arthroplasty, offering many benefits to surgeons during prosthetic implantation.

CAS is a passive device which shows the position of surgical tools and prosthesis. Image-based navigation allows the surgeon to navigate through virtual images on the screen while handling these components [5]. Imageless navigation creates a virtual coordinate system after intraoperative registration, which is then used to guide osteotomy according to the desired alignment [6]. Recent studies have confirmed that CAS is more reliable in achieving precise bone cutting and desired component alignment compared to conventional techniques [7–9]. Nevertheless, there remains potential for human error due to a lack of safety constraints. Consequently, CAS may be better used as a secondary technology particularly with the recent development of RAS. The first-generation RAS is considered active system, where the patient-specific model and corresponding surgical plan are constructed offline prior to commencing the operation [10]. Once activated, the robot arm operates autonomously without real-time guidance. While Semi-active systems allow the surgeon to guide a robotic arm for performing bony preparations and operate within the confines of haptic constraint predetermined by surgical planning [3].

Despite many studies noting improvements in clinical outcomes of joint arthroplasty achieved with the assistance of CAS and RAS systems, other researchers have questioned the tangible benefits of these new technologies. Specifically, some recent studies have reported inconclusive clinical efficiency and low cost-effectiveness [11, 12], which may offset the potentially dubious benefits of CAS and RAS technologies providing better implant positioning and alignment. Nonetheless, both CAS and RAS continued to gain popularity among orthopedic surgeons for arthroplasty procedures. For instance, the proportion of cases using technology-assisted TKA gradually grew from 1.2% in 2005 to 7.0% in 2014 [13], and the clinical uptake of CAS and RAS in THA also increased from 0.5% in 2008 to 5.2% in 2015[14]. Apart from surgeon's preference, patient demand also plays a significant role in such widespread popularization, which is often overlooked and has not been quantified yet.

Google Trends provides an innovative method to capture and analyze overall public interest in an emerging topic area. It is a free, open-source tool based on the most powerful search engine Google, which in this setting can quantify the level of global public interest in and healthcare utilization of a new technology through relative search volumes [15]. In the present study, we used Google Trends to (1) track temporal trends and analyze the seasonality of public interest in RAS and CAS assisted arthroplasty over the last 10 years, and (2) predict the public popularity of RAS and CAS assisted arthroplasty in the next 10 years.

Material and methods

Google trends

Google Trends is a publicly accessible tool for examining online search behavior, powered by Google, the most popular web search engine by far in English-speaking countries. It provides information on trends and variations in online searches, reflecting public interest on a topic area through a user-defined term by relative search volume (RSV). RSV represents the volume of a given search term relative to peak popularity within a selected region and time interval [16]. The results are returned on a scale from 0 (the search term is below 1% of its peak popularity) to 100 (the search term is at its highest peak popularity). For instance, a relative search volume of 70 reflects that the search term returned 70% of its highest search volume during the defined observation time.

Search strategy

Two groups of search terms were selected to capture public interest in CAS and RAS systems, respectively. Keywords utilized for CAS arthroplasty included combinations and permutations of "navigation", "navigate", "navigated", "computer", "joint", "replacement", "arthroplasty" while those for RAS arthroplasty included "robot", "robotic", "joint", "replacement", "arthroplasty". The time interval was set between January 2012 and December 2021. The interest by region option was set to "worldwide" and not limited to a specific geographic area. The category was selected as "health" to better define the medical theme.

Pre-existing trends

To capture pre-existing trends in public interest relating to CAS and RAS joint arthroplasty, linear and exponential growth models were generated using R version 3.5.0. The performance of models was compared by R^2, while the accuracy of models was determined by mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean square error (RMSE). Regression analysis was used to evaluate whether public interest increased or decreased significantly as time progressed.

Seasonal trends

The seasonality of search trends was investigated using time-series analysis and further visualized as box-plots and heat maps, performed using R version 3.5.0 with the "TSstudio" package.

Prediction of future trends

The auto regressive integrated moving average (ARIMA) model was applied to precisely forecast search trends, which fully considered the intrinsic properties of the time series. The ARIMA equation is

$$Y_t = a + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \cdots + \Phi_p Y_{t-p} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \cdots \theta_q \varepsilon_{t-q},$$

Where Φ and θ are the autoregressive and moving average parameters, respectively. Y_t represents the differenced time series, and ε_t is the value of the random shock at time t while α is a constant [17]. The ARIMA model was trained on monthly frequency data by R version 3.5.0 using the auto.arima() function. The algorithm was permitted to iteratively attempt to fit on differenced data (to remove trend) and first seasonal difference (to remove seasonal trend), and automatically choose the best fit. The level of fit was evaluated by Akaike information criterion (AIC) and Bayesian information criterion (BIC). Furthermore, the model accuracy was assessed by mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean square error (RMSE). The Ljung-Box Q test was implemented to judge whether the residuals of the optimal model met the requirements of white noise sequences.

Results

Pre-existing trends

For RAS arthroplasty, the search volume consistently increased during the study period from January 2012 to December 2021 using both linear and exponential models (R^2 value of 0.78 and 0.83 respectively; $P < 0.001$ for both). The exponential model gave a more accurate representation of pre-existing trend in search volume with better fit to RSV data. Additionally, the measures of accuracy by levels of error MAE, MAPE and RSME were lower for the exponential model compared to the linear one (Fig. 1a). In contrast, CAS arthroplasty showed a significant decreasing trend in search volume over the study period by both linear and exponential models ($P < 0.001$ for both). The two models were comparable in goodness of fit (R^2 value of 0.04 for both) with similar values for measures of accuracy of MAE, MAPE and RSME (Fig. 1b).

The overall trends in search volume show lower RSV values for RAS arthroplasty compared to CAS prior to 2014 (Fig. 1c). The intersection of RSV curves occurred during 2014, after while public interest in RAS overtook CAS and continued to increase rapidly to values more than fourfold higher than that 10 years ago. Interest in RAS has far exceeded CAS in 2021, where the latter showed a slow decline in values over the last decade.

Seasonal trends

Seasonal variation by month averaged over the years in the last decade was plotted for RAS (Fig. 2a) and CAS (Fig. 2b) arthroplasty. For RAS, the highest public interest over the course of the year was observed in July and October, while the lowest was in March and December. For CAS, a rise in public interest was observed in May and October, while lower values were seen in January and November.

Supplementing these seasonal variations were heat maps drawn by month, capturing search interest for RAS (Fig. 3a) and CAS (Fig. 3b) over each year of the observation period. RAS showed significant deepening in color in recent years indicative of increasing RSV, while CAS showed relatively uniform color distribution although the overall trend was weaker coloring in the more recent years.

Prediction of future trends

Prediction of future trends in search volume was conducted using the fitted values and forecasting model for RAS and CAS arthroplasty based on ARIMA (Fig. 4a). The Ljung-Box Q test (RAS: $P = 0.88 > 0.05$; CAS: $P = 0.63 > 0.05$) indicated that the residual sequences contained white noise. The performance of the RAS and CAS ARIMA models were considerable (RAS: AIC = 861.32, BIC = 878.00; CAS: AIC = 727.99, BIC = 733.55), and both forecasting models gave acceptable measures of accuracy (RAS: MAE = 6.49, MAPE = 29.34%, RSME = 8.29; CAS: MAE = 3.99, MAPE = 32.29%, RSME = 5.01). The predicted RSV values for the next 10 years (Fig. 4b) indicated a continuous upward trend for RAS arthroplasty, with search volumes predicted to nearly double between 2020 and 2030. Meanwhile, a mostly stable with slight downward trend was predicted for CAS arthroplasty in the next 10 years.

Discussion

RAS and CAS are two prominent applications of new technologies in surgical assistance for arthroplasty, which have gained increasing popularity in recent years. Our analysis on public interest in these two technologies demonstrated a

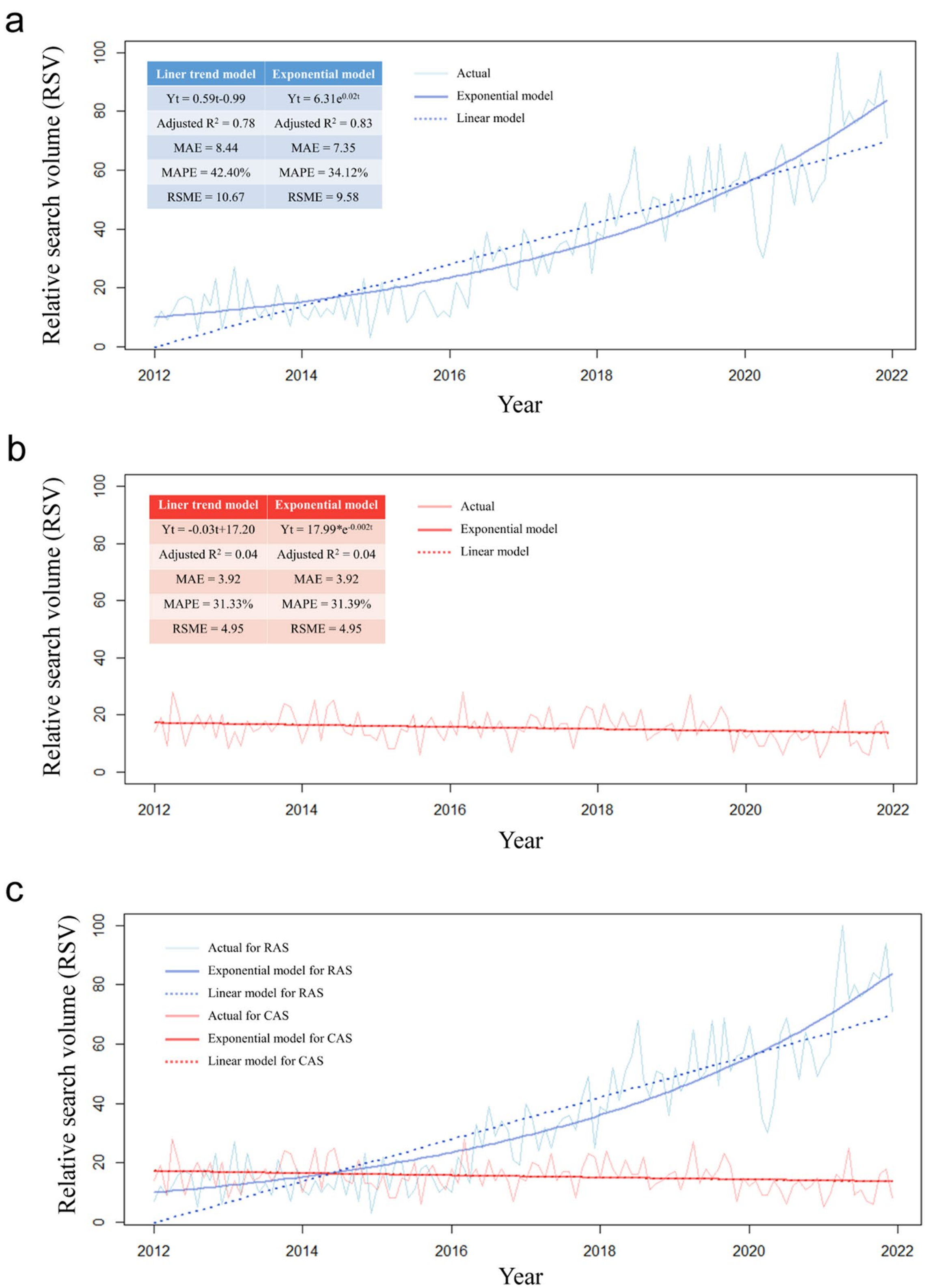

Fig. 1 **a** Linear and exponential models for public interest in RAS arthroplasty. **b** Linear and exponetional models for public interest in CAS arthroplasty. **c** A comparsion of pre-existing trend between RAS and CAS arthroplasty. *RAS* robotic assisted surgery, *CAS* computer-assited navigation system, *RSV* relative search volume, *MAE* mean absolute error, *MAPE* mean absolute percentage error, *RSME* root mean square error

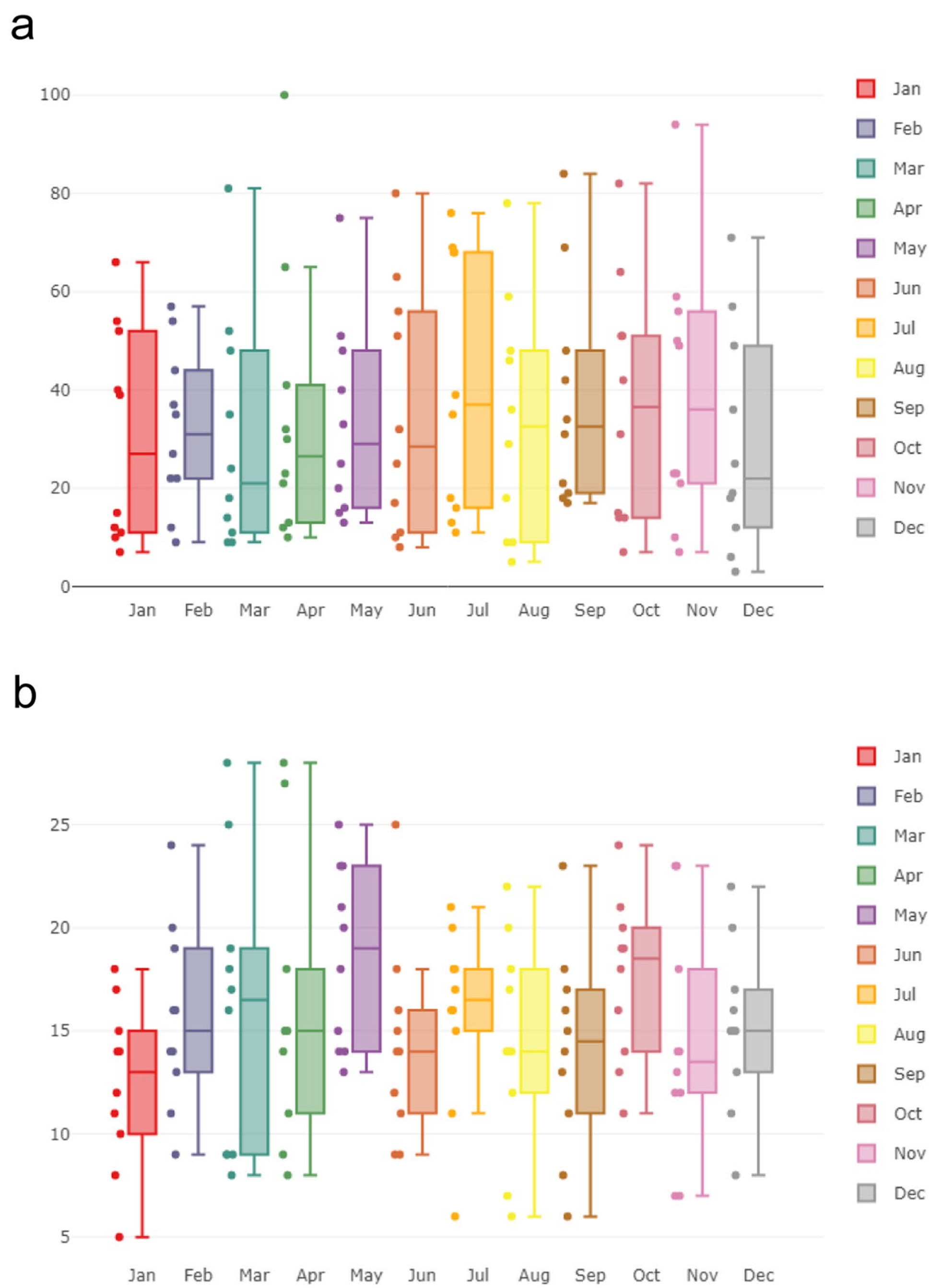

Fig. 2 **a** Box-plot of seasonality for public interest in RAS arthroplasty. **b** Box-plot of seasonality for public interest in CAS arthroplasty

continued increase in internet search volume on RAS arthroplasty, compared to a slight downward trend for CAS arthroplasty over the last decade. These findings were shown to be significant and consistent in both linear and exponential models. Based on time series analysis and ARIMA models, we predicted that search volume for RAS arthroplasty will nearly double from now until 2030, whereas that for CAS arthroplasty will likely remain stable.

In line with a recent study conducted by Brinkman et al. [18], which also applied Google Trends in the field of joint arthroplasty, our results pointed to an exponential increase in RAS arthroplasty over a 10-year period. Our study provided a broader perspective by comparing robotic assistance with navigation technology instead of focusing solely on the former, and expanding our search volume findings globally instead of limiting to the US. It is worth noting that although the exponential model could describe a rough trend in the data, it was unable to make precise future predictions without incorporating time series characteristics, which are dynamic and include adjacent dependent observations [19]. Using ARIMA models, our study was the first to present accurate forecasting of public

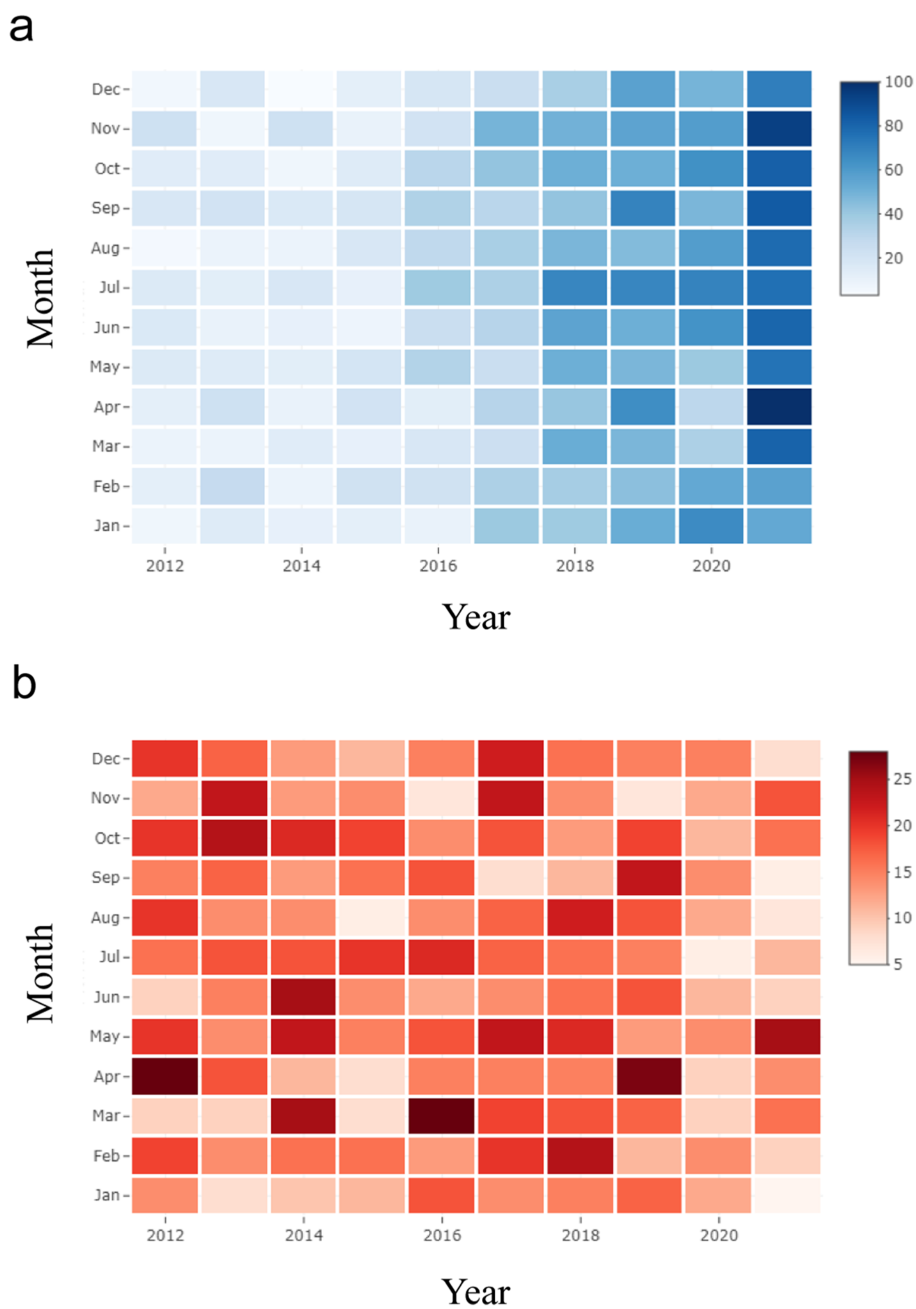

Fig. 3 **a** Heat map of seasonality for public interest in RAS arthroplasty. **b** Heat map of seasonality for public interest in CAS arthroplasty

interest in RAS and CAS arthroplasty that incorporates time series characteristics.

The increasing public appreciation of RAS with time in recent years compared to CAS is an interesting phenomenon, particularly given that new technologies often face some pushback during their first years of use. Navigation technology has been used clinically for more than 15 years in many areas of orthopedic surgery to assist the placement of cutting guides, instruments and implants, which can increase the accuracy of bony resections [5, 6]. However, navigation cannot fundamentally avoid errors caused by manual control during the operation, since only visual feedback and warnings can be provided by this technology. To date, there are three types of robotic technologies in clinical use: the active system (invented and applied as early as 1992), passive system (hardly used due to the potential for human errors similar to CAS), and semi-active system (currently the most mature and widely applied RAS in joint arthroplasty) [3]. With the more recent rapid evolution of RAS to overcome the inaccuracy of manual positioning, navigation may to some extent become a secondary technology [20], causing it to be not as widely used in clinical practice over the last decade especially for hip arthroplasty [21]. Clark et al. [22] retrospectively compared these two technologies

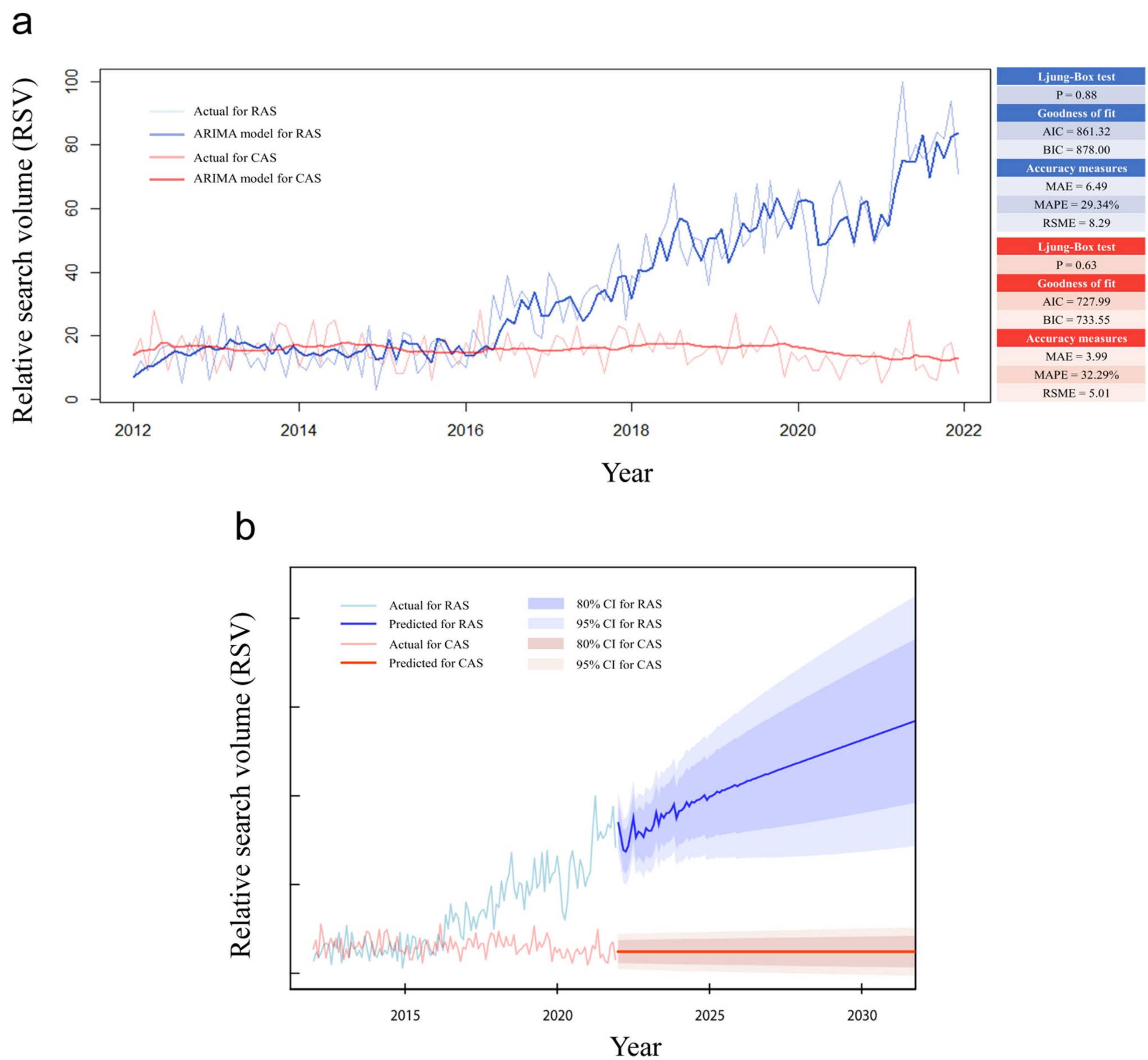

Fig. 4 **a** ARIMA models for public interest in RAS and CAS arthroplasty. **b** The prediction of public interest in RAS and CAS arhtroplasty in the next 10 years. *RAS* robotic assisted surgery, *CAS* computer-assited navigation system, *RSV* relative search volume, *MAE* mean absolute error, *MAPE* mean absolute percentage error, *RSME* root mean square error

in total knee arthroplasty, and found that RAS (52 patients) led to decreased navigation time, fewer femoral malalignment and shorter hospitalization length compared to CAS (29 patients). Our previous network meta-analysis also demonstrated the best mechanical axis restoration with RAS, followed by CAS, and finally the conventional technique in total knee arthroplasty [23].

It is worth noting when interpreting the results of this study that patient interest may not necessarily reflect the superiority of a new or emerging technology, due to the difficulty in disseminating a realistic or factual understanding of health-related information to the general public [18]. "Science hype" on the internet has existed since searching online and freely shared information became increasingly accessible to the public [24]. However, this also led to risks in potentially misguiding public perceptions as patients lacking a professional background tended to exaggerate their understanding of the advantages or disadvantages of a specific treatment. Therefore, it is important to understand from a scientific and clinical perspective whether RAS actually provides superior efficiency, accuracy and/or functional outcomes over CAS or conventional techniques to match with its continuously increasing public interest. If not, then experts should guide patients to correctly understand the pros and cons of this new technology, avoiding misinformation and unrealistic preoperative expectations. Many recent studies provided evidence that robotic systems could optimize component positioning and reduce alignment outliers in knee arthroplasty [25, 26]. Likewise, such benefits on alignment were found in robotic hip arthroplasty, reflected by improvements in safety zone, offset, and limb length discrepancy [27, 28]. A large body of evidence has suggested that neutral alignment and accurate implant positioning can improve clinical outcomes of joint arthroplasty [29, 30]. Nevertheless, these inferences on the superiority of RAS have been pieced together from existing evidence and remain to be verified through high quality clinical studies.

Early interest in RAS might have been somewhat unsubstantiated due to promotion by the manufacturers of these technologies. The majority of clinical studies with mid- to long-term follow-up on robotic arthroplasty reported the historic robotic systems, such as ROBODOC and CASPAR. These active systems operate autonomously under surgical supervision without real-time guidance, which can only be controlled by surgeons using an emergency manual override button once activated [3, 31]. These systems could result in iatrogenic soft tissue injuries associated with increased risk of technical failure, additional operation time, and complications [32, 33]. Such factors may partially explain why the better alignment accuracy offered by active robotic systems often failed to equate to an improvement in clinical outcomes. With recent evolutions in robotic technology, semi-active robotic systems are now the predominant choice, which have demonstrated greater technical reliability compared to their predecessors due to their haptic feedback, likely accounting for their early functional benefits [31, 34, 35]. Although long-term functional outcomes remain to be reported, the current benefits seen during the early postoperative phase should be considered when assessing the future development prospects of robotic arthroplasty.

Our study also investigated the seasonality of search volumes for RAS and CAS, which showed the highest public interest in October over the course of the years analyzed for both technologies, while months with the lowest search volumes diverged without a regular pattern. These results do not provide definitive trends regarding the seasonality of public interest on RAS and CAS, as there was no significant disparity in search volume among different months over the year and the standard deviation of data in each month was considerable, particularly for RAS. Another complicating factor was that the global data analyzed included both northern and southern hemispheres with opposite seasonal variations, although the northern hemisphere was likely the dominant factor considering population size disparities. Heat maps showed relatively uniform color distribution for CAS arthroplasty compared to prominently deepening color for RAS arthroplasty in more recent years, consistent with the trends in public interest on these two technologies reflected by our prediction models. Also worth noting was a sharp decline in public interest in robotic arthroplasty at the beginning of 2020, which might have been influenced by the COVID-19 global outbreak [36]. Conversely, public interest in CAS were relatively unaffected by the pandemic, again suggesting that CAS was not as popular as RAS in this recent time period from the patients' perspective.

Some limitations of our study should be considered when interpreting the findings. First, although Google is the most frequently used search engine in regions where English is the main language, it is not used in many regions around the world particularly in some Asian countries with a sizeable population. This may have introduced some selection bias in our study. Second, although online search volume is a good reflection of public interest in a technology and patient requests, it is not an indication of actual clinical utilization of RAS or CAS in arthroplasty. The findings of our study therefore should not be interpreted as a preference for surgeons or healthcare providers, and does not suggest better efficacy for either technology over the other. Last, there is currently no standardized procedure for data collection in Google Trends analysis. More guidance by the developer is warranted for researchers to conduct similar studies in the future using a more optimized search strategy [16].

Conclusion

Over the last decade, public interest in RAS arthroplasty showed a continued increase, compared to a slight downward trend for CAS arthroplasty. It's predicted that search volume for RAS arthroplasty will nearly double from now until 2030, whereas that for CAS arthroplasty will likely remain stable. High-quality studies are needed to further verify whether RAS actually provides superior clinical benefits over CAS or conventional techniques, which matches with its increasing public interest.

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Data availability All data included in this study are available upon request by contact with the corresponding author.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval None applicable.

Consent to participate None applicable.

Consent to publish None applicable.

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