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Original Article

Mapping theme trends and recognizing research hot spots in the use of ultrasound in orthopaedics: a bibliometric analysis of global research

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Abstract: Background: In the past decade, ultrasound has been increasingly used in the field of orthopaedics. The purpose of this study is to inspire future research in this field by analyzing the publications relating to ultrasound research in orthopaedics. Methods: All relevant articles published between 2009 and 2020 were retrieved from Web of Science. Statistical Package for Social Science and GraphPad Prism 8 software were used to generate and analyse diagrams. VOSviewer software and CiteSpace were employed to visualize the research trends based on co-occurring keywords. Finally, we obtained information about relevant clinical randomized controlled trials (http://clinicaltrials.gov.com/). Results: The United States had the most publications in this field and the most citations and the highest H-index. Furthermore, Skeletal Radiology published the most papers related to the use of ultrasound in orthopaedics, Ozcakar L published the most papers, and a study by Kwon, YM had the highest citation frequency. The keywords "MRI", "complication", "female" and "male" were identified as being indicative of emerging topics. Conclusions: While the contribution of United States to publications in this field has been substantial, the future contributions of China cannot be ignored. Moreover, it is hypothesized that diagnostic and epidemiological aspects may become hotspots.

Keywords: Ultrasound, orthopaedics, publications, citation frequency, bibliometrics

Introduction

As a diagnostic tool, ultrasound has many advantages, including being convenient, fast, and non-invasive, and has been widely used in many medical fields [1]. For example, ultrasound has long played an important role in the diagnosis of thyroid tumours. Ultrasound is also an accurate tool for the diagnosis of breast cancer [2], atherosclerosis [3] and hepatic fibrosis [4]. During the coronavirus disease 2019 (COVID-19) pandemic, it is challenging to transport patients to department of radiology for computed tomography (CT) assessments; therefore, bedside ultrasound has become the main method of diagnosis in the intensive care unit (ICU) [5]. The use of ultrasound as a treatment has also reduced the performance of unnecessary surgeries and alleviated pain. For example, the performance of urinary calculi surgery has decreased because of the use of the ultrasonic lithotripsy technique [6]. The use of ultrasound-guided lateral thoracolumbar interfascial plane block also reduces pain in patients undergoing lumbar spine fusion surgery [7]. Orthopaedics is a comprehensive field that includes multiple subspecialties that focus on specific areas, such as trauma, joints, and the spine. In the EU in 2010, 22 million women and 5.5 million men were affected by osteoporosis [8]. Therefore, orthopaedics has long been an important area of medical research. Recently, the use of ultrasound in the field of orthopaedics has received increasing attention. For example, quantitative ultrasound has been shown to have unique advantages in the identification of the probability of osteoporotic fracture [9]. Similarly, ultrasound is also useful in

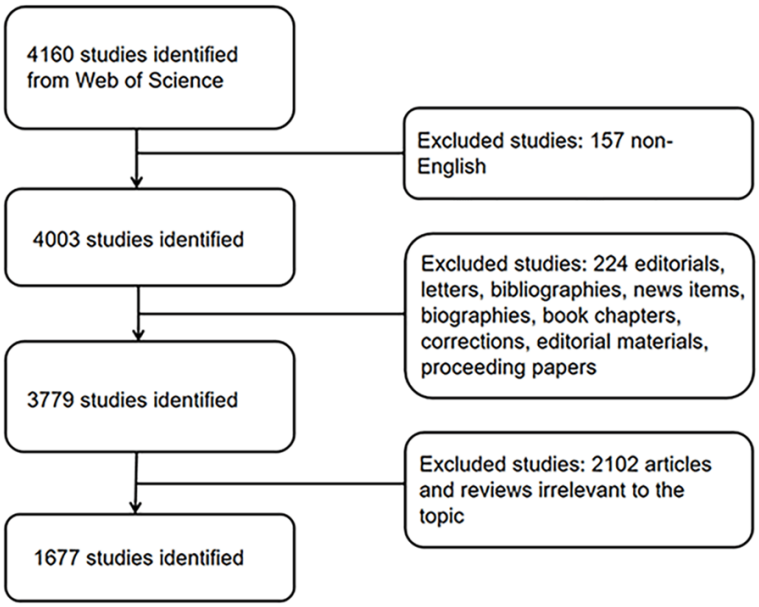

Figure 1. Flow diagram of the inclusion process. The detailed process of screening and inclusion.

patients with femoral head necrosis [10]. Given the increasing pace of research on the use of ultrasound in orthopaedics, it is important to identify the relevant trends and hotspots.

Bibliometrics is a useful method of quantitatively and qualitatively evaluating trends in research activity over time that relies on literature databases and metrics. It provides a convenient way to understand developing trends in a specific field and the ranking of academic groups and individual researchers [11]. Similarly, bibliometrics can also provide supporting evidence that can be used when creating policies and making decisions [12]. Bibliometric research methods have been widely used to investigate research on diabetes [13], cardiovascular disease [14], gastrointestinal diseases [15] and respiratory medicine [16]. Through a comprehensive analysis of the author, country, H index, citation amount, publication time and other issues of the selected articles, the contributions of academic groups and individual researchers are evaluated objectively. Similarly, through the integration and analysis of the keywords of the included articles, the words with high frequency and the words newly emerged in recent years, which were treated as hotspots, were selected to provide supporting evidence with regard to future development trends. The present study aimed to comprehensively analyse the progress of research on the use of ultrasound in orthopaedics based on the articles in Web of Science (WOS). We performed a bibliometric analysis to identify the trends in research in this field and predict the possible future hotspots.

Julien Dartus et al. performed a bibliometric analysis of orthopaedic research over the past two decades in France [17], and Xiao Zhai et al. also used bibliometric methods to report the trends in publications on the use of ultrasound on spines from 1994 to 2015 [18]. To date, no study has reported research on the use of ultrasound in orthopaedics as a whole. We comprehensively reviewed the publication trends and analysed future hotspots in the field of the use of ultrasound in orthopaedics.

Materials and methods

Data sources and search strategies

Studies published from 2009 to 2020 were included. It is widely accepted that the online database Science Citation Index-Expanded (SCI-E) of Thomson Reuters' WOS is one of the most suitable tools for collecting data; therefore, all publications were obtained from this database. To avoid omissions owing to the rapid updating of the database, we completed the search in one day, September 19, 2020. The search strategy was as follows: TS = ((ultrasound) OR ultrasonography) OR (ultrasonic) OR (sonography)) AND Web of Science Categories = Orthopaedics AND Language = English. Only original articles and reviews with standard peer reviews were included in our research. The original articles and reviews were reviewed by other experts and scholars in the same field; other types of studies and repetitive articles were excluded. The process was carried out by two authors. If there is a disagreement over the inclusion of a paper, the final decision is made by the experienced corresponding author. The study selection process is shown in **Figure 1**. In clinical randomized controlled trials, the articles with keywords "Ultrasound" and "ortho-

paedics" were selected. The limitations also included completed randomized controlled trials. The results showed that there were a total of 7 trials.

Data collection

All data were extracted from the identified publications by three authors (WS, WKW and ZZT). The extracted data included titles, keywords, authors, publication dates, countries and regions of origin, institutions, journals, number of citations, H-index, and so on. Microsoft Excel 2016 (Redmond, Washington, USA), Statistical Package for Social Sciences (SPSS, version 24, IBM Corporation, USA), GraphPad Prism 8 (GraphPad Prism Software Inc., San Diego, CA), VOSviewer version 1.6.12 (Leiden University, Leiden, the Netherlands), CiteSpace version 5.6. R5 64 bit (Drexel University, Philadelphia, PA, USA), and the Online Analysis Platform of Literature Metrology (http://bibliometric.com/) were used to analyse and present the data and generate the figures. Meanwhile, the gross domestic products (GDPs) of the countries of origin were retrieved from the World Bank website. Data about completed clinical randomized controlled trials about the use of ultrasound in orthopaedics were collected from the clinicaltrials.gov website (http://clinicaltrials.gov.com/).

Bibliometric analysis

Thomson Reuters' WOS is a large collection of studies, especially those focused on biomedicine, which supported our selection of the WOS. The relative research interest (RRI) was defined as the number of publications in a particular research field divided by the total publications across all fields per year. The impact factor (IF) was obtained from the information provided by the journal citation reports (JCRs) published in 2020. It is widely accepted that the H-index plays an important role in evaluating the scientific research impact of a researcher or a country. Especially in medicine, the H-index of articles serves as a tool to measure academic productivity. The H-index means that a researcher or a country has published at least H papers, and that each paper has been cited in other publications at least H times; The H-index is the most important metric among those we collected (total citation count, citations per paper, and total paper count) for the assessment of scientific achievement.

Citespace is a practical statistical software. We used the links between nodes in the map to determine the bibliometric characteristics, such as references, institutions, authors and terms, and we also analysed the potential trends in future research. This software was also used to extract the keywords. VOSviewer, which uses the Java programming language, is a convenient mapping tool that is widely used for co-citation network analyses and visualization. The technique used for map construction was based on a co-occurrence matrix.

Results

In all, 1,677 articles published from 2009 to 2020 met our inclusion criteria, with the United States ranking first in the number of publications at 469 (27.9%), followed by England at 164 (9.8%) and Japan at 160 (9.5%). By comparing the number of papers published per year, we found that the largest number of publications occurred in 2019, with 194 publications (11.6%) (**Figure 2A**). When the numbers of publications across all fields were considered, the global interest in the use of ultrasound in orthopaedics measured by the RRI started to increase in 2016, reaching 0.045% in 2019; interest peaked in 2019 (**Figure 2B**). We believe that growth will accelerate in this field in the future. The cooperative relations between countries were visualized (**Figure 3**). Unsurprisingly, as it was the country with the most publications, the United States had the closest ties to other countries.

Growth trends in publications

The cumulative number of publications worldwide and in the top 6 countries, as well as the corresponding model fitting curves, is shown in **Figure 4**. Based on these growth curves, we found that the global growth in publications was rapid, as was the growth in several countries, such as South Korea and China (**Figure 4F** and **4G**). The number of papers published by those countries per year has grown rapidly in recent years, especially in China, which is predicted to have a faster growth in publications in this field than other countries over the next twenty years (**Figure 4G**). Although some countries currently lead in terms of the number of papers published, their growth rates are predicted to decline over the next twenty years, as in the United States and Japan (**Figure 4B** and **4D**).

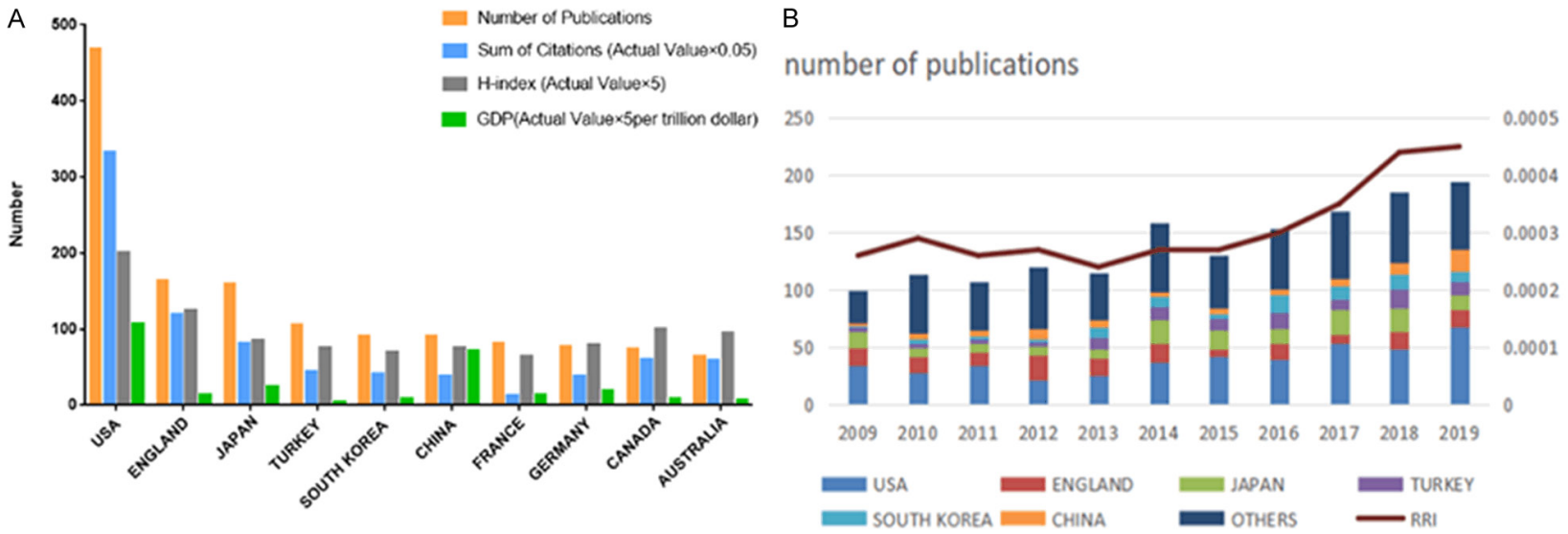

Figure 2. Contributions of different countries/regions to the research on the use of ultrasound in orthopaedic research. A. The number of publications, citation frequency (×0.05), H-index (×5) and GDP (×5, per trillion dollar) in the top 10 countries or regions; B. The number of publications worldwide and the time course of the relative research interest in the use of ultrasound in orthopaedics.

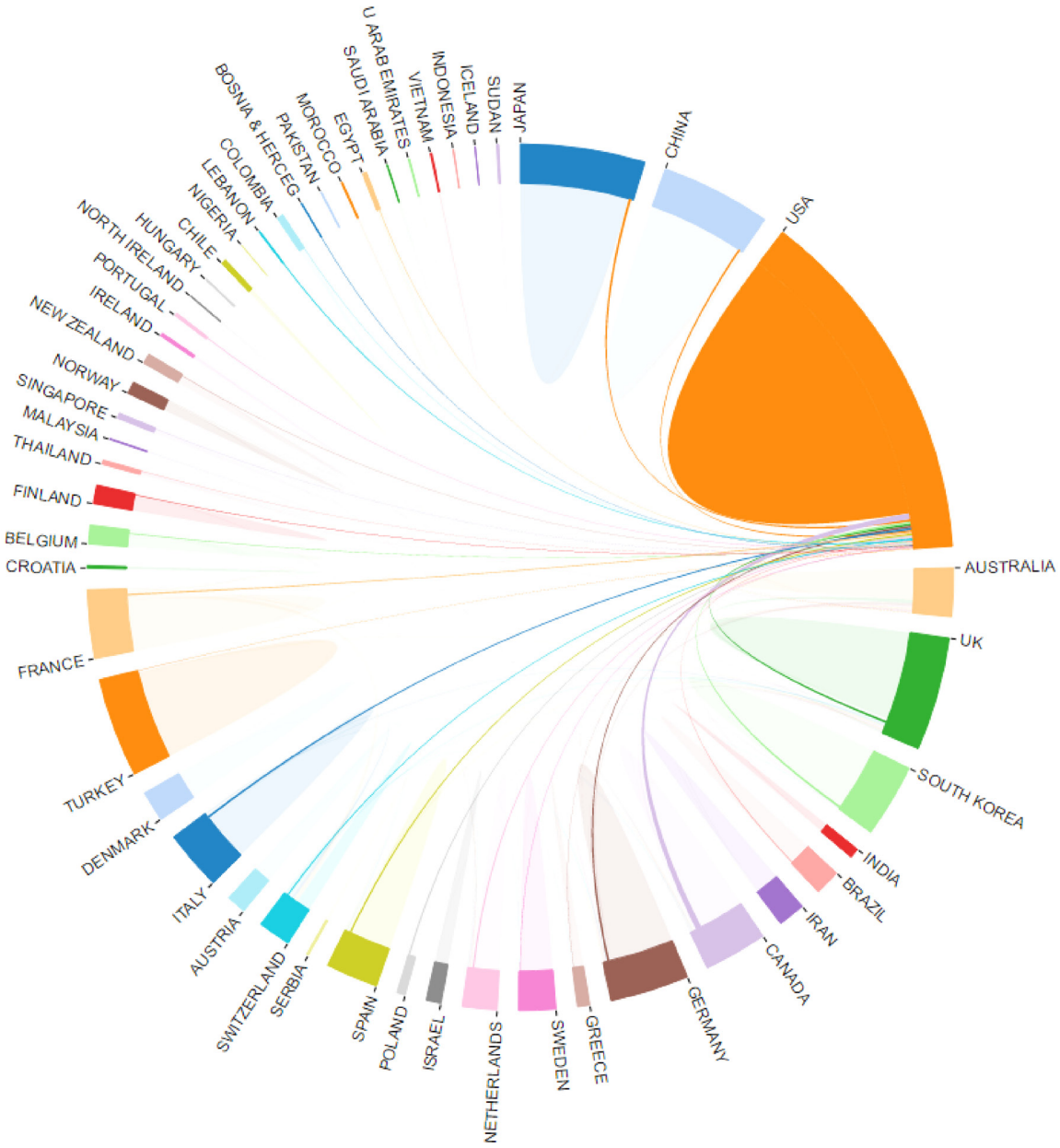

Figure 3. The network of cooperation among countries/regions in research on the use of ultrasound in orthopaedics. The cooperative relations between countries/regions were visualized.

Citations and H-index analysis

According to the Journal Citation Report from the WOS database, all articles related to the use of ultrasound in orthopaedics were cited 20,311 times since 2009 (18,730 without self-citations), with an average citation frequency of 12.11 times per paper. The United States accounted for 32.7% of the total citations, i.e., 6650 citations (6,387 without self-citations), and had an H-index of 40. The number of citations from England was 2,397 (2,343 without self-citations), with an H-index of 25, which meant that England is ranked second. Although the number of publications from Canada ranked ninth, the citation frequency was 1,213, with an H-index of 20, and thus Canada ranked fourth (**Figure 2A**).

Journals with publications on the use of ultrasound in orthopaedics

More than one-third of the papers on this topic were published in 10 journals (660, 39.36%).

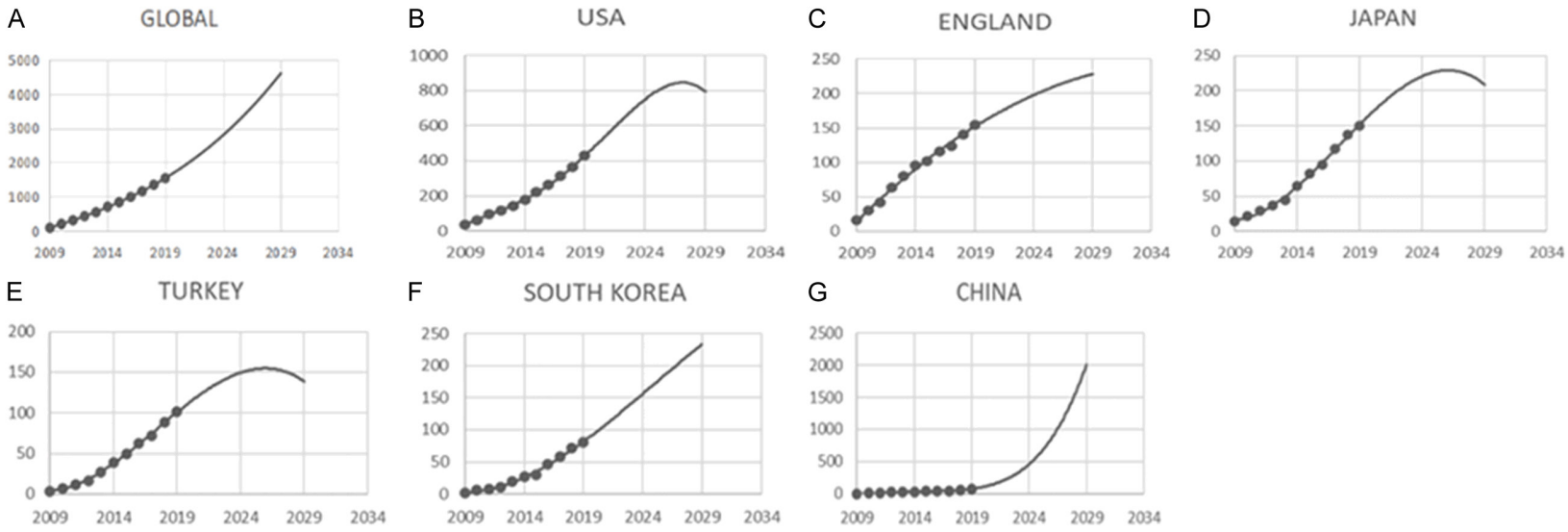

Figure 4. Model fitting curves for the growth trends in publications on the use of ultrasound in orthopaedics. A. Global; B. USA; C. England; D. Japan; E. Turkey; F. South Korea; G. China.

Table 1. The top 10 journals with publications on the use of ultrasound in orthopaedics

SCR*	Journal	Contribution (%)	H-index	IF**
1st	Skeletal Radiology	202 (12.0)	25	1.618
2nd	BMC Musculoskeletal Disorders	83 (4.9)	17	1.879
3rd	Journal of Shoulder and Elbow Surgery	69 (4.1)	19	2.817
4th	Knee Surgery Sports Traumatology Arthroscopy	57 (4.0)	15	3.116
5th	American Journal of Sports Medicine	52 (3.1)	26	5.810
6th	Journal of Back and Musculoskeletal Rehabilitation	43 (2.6)	8	0.821
7th	Clinical Biomechanics	42 (2.5)	15	1.624
8th	Journal of Hand Surgery-American volume	39 (2.3)	10	2.124
8th	Orthopaedics & Traumatology: Surgery & Research	39 (2.3)	8	1.809
10th	Journal of Foot and Ankle Surgery	34 (2.0)	6	1.598

SCR, standard competition ranking; *IF,* impact factor. *Equal journals were assigned the same rank, and then a gap was left in the ranks. **The impact factor was reported obtained from the journal citation reports (JCR) 2020.

Table 2. Top 20 institutes with the most publications on the use of ultrasound in orthopaedics

Rank	Institution	Contribution (%)	Country
1st	Mayo Clinic	1.968	USA
2nd	Hospital for Special Surgery	1.431	USA
3rd	Hacettepe University	1.371	Turkey
4th	Hong Kong Polytech University	1.132	China
5th	Washington University	1.013	USA
6th	New York University	0.954	USA
6th	University of Sao Paulo	0.954	Brazil
8th	McMaster University	0.894	Canada
9th	University Pittsburgh	0.834	USA
10th	Chinese University Hong Kong	0.775	China
10th	Kyoto University	0.775	Japan
12th	Massachusetts General Hospital	0.715	USA
12th	Thomas Jefferson University	0.715	USA
12th	Korea University	0.715	Korea
12th	University of California at San Francisco	0.715	USA
12th	University of Michigan	0.715	USA
17th	Harvard University	0.655	USA
17th	National Taiwan University	0.655	China
17th	Northwestern University	0.655	USA
17th	University of Alberta	0.655	Canada

The most papers were published in Skeletal Radiology (IF = 1.618), with 202 records. BMC Musculoskeletal Disorders (IF = 1.879) ranked second in terms of the number of publications. The journals that ranked first and second in terms of IF were American Journal of Sports Medicine (IF = 5.810), and Knee Surgery Sports Traumatology Arthroscopy (IF = 3.116), which had 52 and 57 publications on the use of ultrasound in orthopaedics and ranked fifth and fourth in terms of the number of publications, respectively. Meanwhile, the American Journal of Sports Medicine also ranked first in terms of the H-index. The top 10 journals with the most publications on the use of ultrasound in orthopaedics are listed in **Table 1**.

Institutions with research publications on the use of ultrasound in orthopaedics

The Mayo Clinic in the United States had the most publications among institutions worldwide, with 33 papers, which accounted for 2.0% of all publications. Within the list of the top 20 institutions in this field, US institutions account for over half; in addition, three institutions were in China, two were in Canada, one was in Turkey, one was in Brazil, one was in Japan, and one was in Korea (**Table 2**).

We can also obtain information about the timing of the publication of all articles by various institutions (**Figure 5A**). The blue colour indicates that the articles belonging to that institution were published relatively early, while the red colour indicates more recent publications. As shown in this figure, the Mayo Clinic, which had the most publications among institutions worldwide, has not reduced the number of pub-

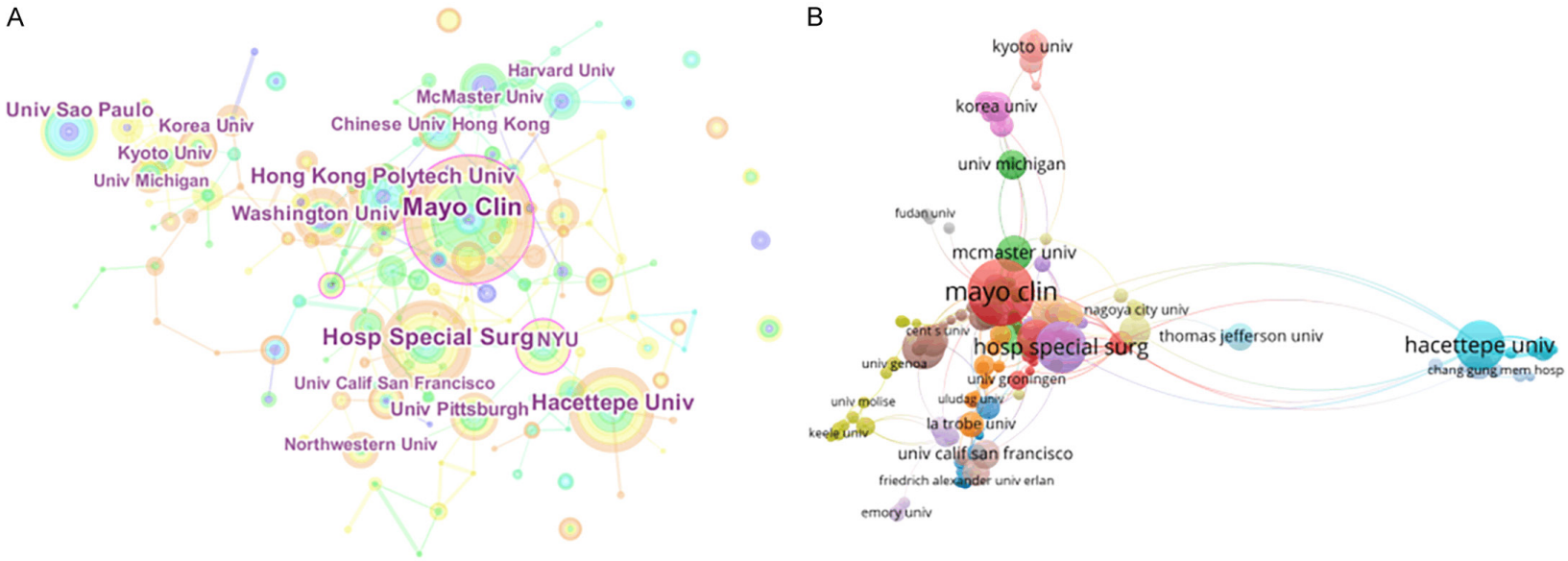

Figure 5. The distribution of institutions engaged in research on the use of ultrasound in orthopaedics. A. The network of institutions by CitesSpace; B. The network of institutions by VOSviewer.

Table 3. Top 10 authors with the most research on the use of ultrasound in orthopaedics

Author	Country	Affiliation	No. of Publications	No. of Citations
Ozcakar, L	Turkey	Hacettepe University	13	76
Adler, RS	USA	Cornell University	11	363
Maffulli, N	England	Mile End Hospital	11	190
Jacobson, JA	USA	University Michigan	9	262
Lee, SH	South Korea	Inje University	9	31
Mazzer, N	Brazil	University of Sao Paulo	9	44
Zheng, YP	China	Hong Kong Polytech University	9	218
Akkaya, N	Turkey	Pamukkale University	8	77
Amadio, PC	USA	Mayo Clinic	8	197
Barbieri, CH	Brazil	University of Sao Paulo	8	40

lications it has produced in recent years. In **Figure 5B**, the size of the circle represents the number of publications from that institution; the top three institutions were the Mayo Clinic, Hospital for Special Surgery and Hacettepe University.

Authors with research publications on the use of ultrasound in orthopaedics

A total of 95 papers that were published by the top 10 authors accounted for 5.7% of all literature in this field. Ozcakar L, from the University of Hacettepe, published 13 papers related to the use of ultrasound in orthopaedics, ranking first in terms of the number of publications. Adler RS and Maffulli N published 11 papers and ranked second among all authors. As shown in **Table 3**, among the top 10 authors with the most publications on the use of ultrasound in orthopaedics, there were 3 authors from the United States, 2 from Turkey, 2 from Brazil, 1 from China, 1 from England and 1 from South Korea. Notably, the highest citation frequency was identified for publications written by Adler, RS from Cornell University in the United States (363 times) (**Table 3**).

Analysis of keywords in publications on the use of ultrasound in orthopaedics

We analysed the keywords extracted from 1,677 publications using VOSviewer. As shown in **Figure 6A**, 66 keywords, defined as terms that occurred more than 60 times within titles and abstracts in all papers analysed, were identified and classified into three clusters, namely, diagnosis, treatment and epidemiology. Within the cluster of diagnosis, the following keywords were frequently mentioned: diagnosis (338 times), case (337 times), examination (330 times), value (270 times), sensitivity (163 times), and MRI (159 times). In the cluster of treatment, the relevant keywords were treatment (459 times), group (440 times), pain (391 times), month (318 times), and score (316 times). In the cluster of epidemiology, the primary keywords were measurement (302 times), change (285 times), thickness (215 times), correlation (197 times), and image (189 times) (in Supplementary Table 1). Details of the co-occurrence analysis of all keywords are shown in **Figure 6A**.

Figure 7 shows additional information about keywords. The most salient keyword was exercise; its strength was 7.4015. It became more important from 2013 to 2016. More recently, the newest salient keyword was instability, which grew in importance from 2017 and 2020, with strength of 4.1026. The popularity of keywords such as bone, articular cartilage, thickness and radiography lasted the longest (6 years), with an increase in strength from 2009 to 2014.

Discussion

Trends in research on the use of ultrasound in orthopaedics

In terms of the publication volume of all countries, the United States ranked first (**Figure 2**), while China had the fastest growth rate (**Figure 4G**). We speculate that the reason for this phenomenon is related to GDP (**Figure 2A**). We also found that developed countries published more research, such as the United States, England and Japan (**Figure 2A**). This shows that countries leading in science and

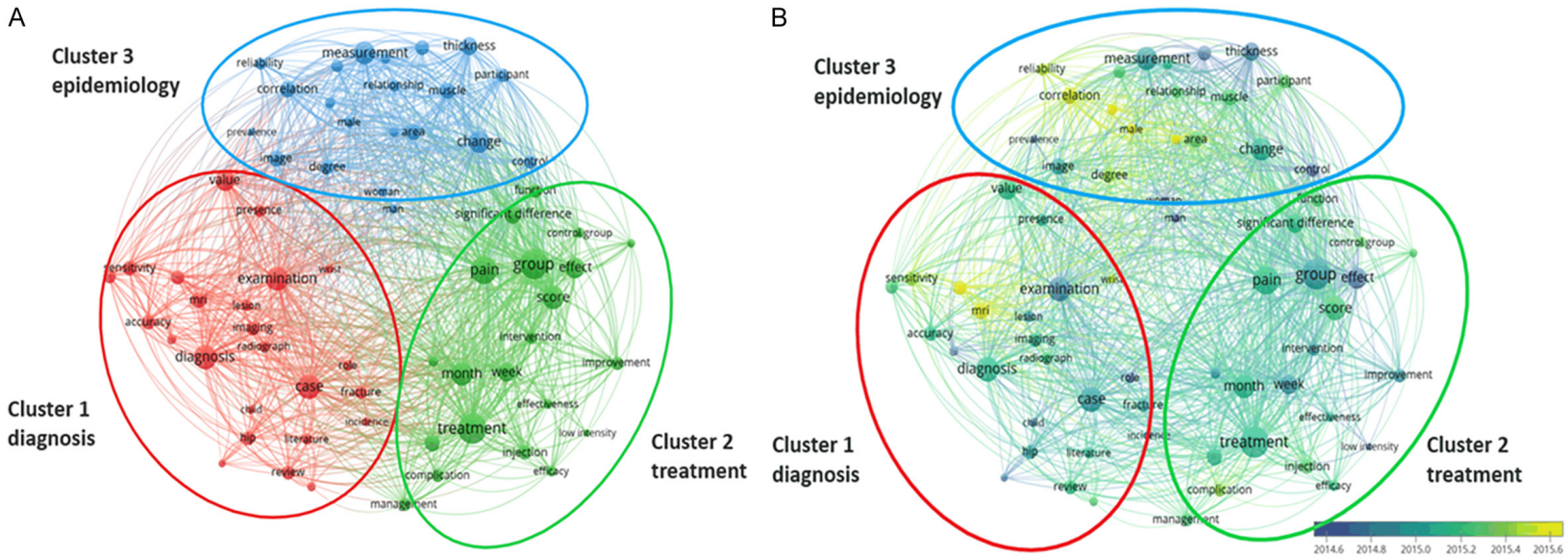

Figure 6. The co-occurrence analysis of all keywords in publications on the use of ultrasound in orthopaedics. A. Mapping of the keywords in publications on the use of ultrasound in orthopaedics. The words were divided into 3 clusters marked with different colours: "Diagnosis" (on the left in red), "Epidemiology" (on the top in blue), and "Treatment" (on the right in green). The size of the circle represents the frequency of the keywords. B. The distribution of keywords is presented according to the average timing of their appearance. Blue represents early appearance, and yellow represents late appearance. Two keywords were considered co-occurring if they both occurred on the same line in the corpus file. A smaller distance between two keywords indicated relatively more co-occurrences of the keywords.

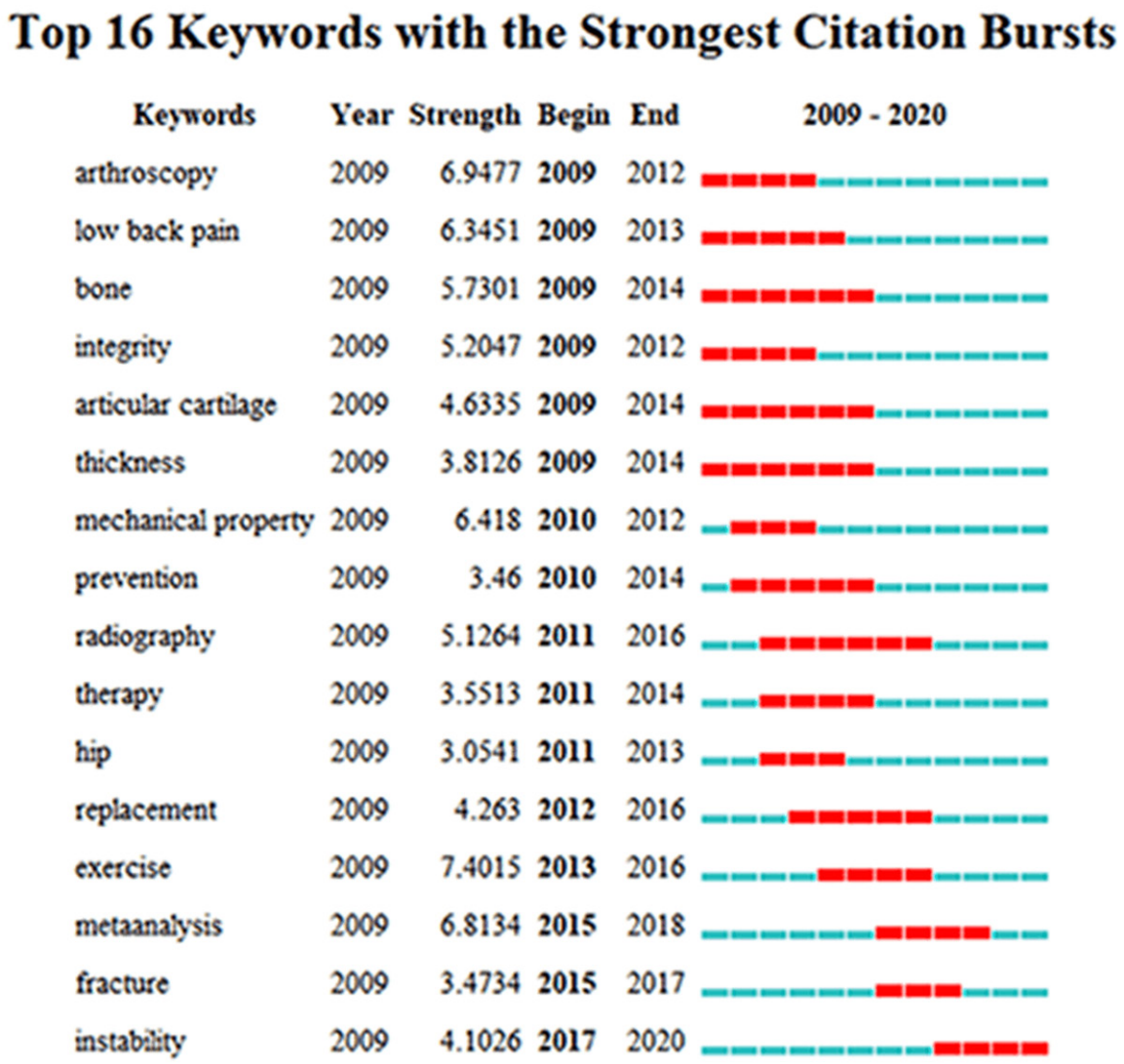

Figure 7. The top 16 keywords with the strongest citation bursts from 2009 to 2020. The red bars represent frequently cited keywords during this time period. The green bars represent infrequently cited keywords.

technology are more likely to be involved in exploring the uses of ultrasound. Improvements have emerged in ultrasound technologies in developed countries, such as the invention of ultrasound and microbubble therapy [19], which can efficiently increase cell membrane permeability, resulting in enhanced tissue distribution and intracellular drug delivery of molecules; small probes [20]; and the combination of ultrasound, X-ray and MRI [21]. New technologies often appear in developed countries.

Published articles with the highest citation frequencies have the greatest academic impact in a certain field. Detailed information regarding the top ten most frequently cited publications on the use of ultrasound in orthopaedics is provided in **Table 4**. The study published in The Journal of Arthroplasty in 2011 with Kwon, YM as the corresponding author was ranked first, and it reported that in metal-on-metal hip resurfacing arthroplasty, ultrasound is essential as a diagnostic tool [22]. The articles ranked second to fourth were all published in the same journal, the American Journal of Sports Medicine, and they described the application of ultrasound diagnosis for the repair of chronic Achilles tendinopathy, large and massive rotator cuff tears and double-row rotator cuffs, respectively [23-25]. In the top 10 cited articles about the use of ultrasound in orthopaedics, the focus was an evaluation of the effective-

Table 4. Top 10 most-cited studies related to the use of ultrasound in orthopaedics

Title	Corresponding Authors	Journal	Publication Year	Total Citations	Corresponding Author's Country
"Asymptomatic" Pseudotumours After Metal-on-Metal Hip Resurfacing Arthroplasty	Kwon, YM	Journal of Arthroplasty	2011	216	USA
One-Year Follow-up of Platelet-Rich Plasma Treatment in Chronic Achilles Tendinopathy A Double-Blind Randomized Placebo-Controlled Trial	de Jonge, S	American Journal of Sports Medicine	2011	176	The Netherlands
Factors Affecting Healing Rates After Arthroscopic Double-Row Rotator Cuff Repair	Tashjian, RZ	American Journal of Sports Medicine	2010	171	USA
When Do Rotator Cuff Repairs Fail? Serial Ultrasound Examination After Arthroscopic Repair of Large and Massive Rotator Cuff Tears	Miller, BS	American Journal of Sports Medicine	2011	138	USA
Hyaline cartilage involvement in patients with gout and calcium pyrophosphate deposition disease. An ultrasound study	Filippucci, E	Osteoarthritis and Cartilage	2009	138	Italy
The diagnostic value of ultrasonography-derived edema of the temporal artery wall in giant cell arteritis: a second meta-analysis	Sfikakis, PP	BMC Musculoskeletal Disorders	2010	134	Greece
The Sensitivity and Specificity of Ultrasound for the Diagnosis of Carpal Tunnel Syndrome: A Meta-analysis	Fowler, JR	Clinical Orthopaedics and Related Research	2011	116	USA
Long-term Survivorship of Rotator Cuff Repairs Using Ultrasound and Magnetic Resonance Imaging Analysis	Kluger, R	American Journal of Sports Medicine	2011	104	Austria
Prevalence and characteristics of asymptomatic tears of the rotator cuff an Ultrasonographic and Clinical study	Moosmayer, S	Journal of Bone and Joint Surgery-British Volume	2009	104	Norway
Prospective analysis of arthroscopic rotator cuff repair: Prognostic factors affecting clinical and ultrasound outcome	Nho, SJ	Journal of Shoulder and Elbow Surgery	2009	103	USA

ness of ultrasound for the treatment of a disease. These results were clustered into diagnosis, treatment and statistics (**Figure 6A**).

Although there have been few outstanding articles (**Table 4**) and few high-IF journals (**Table 3**) in this field, the RRI was found to be rapidly increasing (**Figure 3**). We analysed the reason for the increase in research interest in the special advantages of ultrasound. On the one hand, hospitals are increasingly using ultrasound devices to reduce exposure to ionizing radiation during examinations, as the general population becomes more aware of the associated risks [13], and for the diagnosis of some orthopaedic diseases, ultrasound is not inferior to CT. For example, ultrasound is more accurate at assessing the early healing of fractures [26]. Ultrasound as a diagnostic and therapeutic method is becoming increasingly popular [27], and the use of bedside ultrasound enables clinicians to achieve a rapid diagnosis in critical and emergency situations. For example, the advent of portable ultrasound has made the rapid diagnosis of soft tissue injury possible in the field [28]. Thus, the acceptance of ultrasound is increasing, and research on the use of ultrasound in orthopaedics is also developing.

Regarding the top 10 institutions and top 10 authors, half of the top 10 institutions were from the United States (**Table 2**), and three of the top 10 authors were also from the United States (**Table 3**). We believe that these findings were related to cooperation between countries. For example, the map based on WOS data showed that the United States has connections with many countries in the field (**Figure 3**); however, other countries have few connections. Therefore, the quality of articles in other countries is lower than that in the United States. This suggests the need for more global cooperation to promote the development and application of ultrasound in the field of orthopaedics.

Research focused on the use of ultrasound in orthopaedics

According to the map based on the analysis of all keywords (**Figure 6A**, **6B**), we found that the keywords were divided into three clusters, namely, diagnosis, treatment and epidemiology. The density of the keywords drew attention to the most important areas of research relating to the use of ultrasound in orthopaedics, revealing an even distribution that was consistent among the three clusters. However, the clusters of diagnosis and epidemiology studies were more recently published, and the potential reasons for this are as follows.

First, the research over the past decade has transitioned towards various aspects of diagnosis rather than just assessing fractures. For example, doctors can use ultrasound to diagnose arthritis [29], dysplasia of the hip [30], subacromial pain syndrome [31], neuromuscular diseases [32] and so on. Furthermore, scientists from different countries have also tried to statistically analyse the use of ultrasound in orthopaedics in recent years. Thus, keywords such as correlation and reliability have emerged within the epidemiology cluster. As shown in **Figure 6B**, research has shifted towards epidemiological studies. For example, in the prediction of the risk of tendon injury, assessment of tendon healing and provision of further insight into tendon physiology, the usefulness of ultrasound was confirmed by epidemiological methods [33]. However, the application of ultrasound in orthopaedics is in its infancy, and more research is needed (**Figure 6A**).

With respect to the latest research hotspots, MRI in the diagnosis cluster was the most recent (cluster 1), which indicates that diagnosis using both ultrasound and with other diagnostic tools to improve diagnostic efficiency is increasingly of interest to researchers. For example, the assessment of fracture healing remains challenging due to a lack of consensus on imaging and clinical criteria as well as the lack of a true gold standard [26]. However, ultrasound signs of healing can be identified as early as 1-2 weeks post fracture. By attaching a position sensing device to the ultrasound probe, 3D reconstructed images can be generated, which can help in the interpretation of complex patterns of fracture healing [34]. In clinical practice, Aspelin P et al. also used ultrasound to diagnose 32 patients with lower-limb soft-tissue injury and found that the diagnostic ability of ultrasound for haematoma was efficient [35]. For the diagnosis of deep tissue damage, MRI has been shown to play a significant role, especially in patients with spinal cord injury [36] and disc herniation [37], compared

with ultrasound and CT. Thus, investigating the combinations of imaging modalities rather than ultrasound alone is likely to be a new hotspot in future research. For example, MRI performed better for the diagnosis of inflammation, but ultrasound was more valuable for the diagnosis of small bone lesions [38]. Therefore, in the treatment of rheumatoid joints, the researchers assessed the disease in three ways: synovitis, osteitis, and erosions. They found that the combination of ultrasound and MRI improved the accuracy of the diagnosis [38].

Complication was the most recent keyword in the treatment cluster (cluster 2). As an important indicator of the therapeutic effect, complications have received a substantial amount of attention from clinicians. In the field of orthopaedics, accurate positioning and navigation during surgery are particularly important; otherwise, nerve and blood vessel damage and other postoperative complications can occur, leading to a poor prognosis. For example, when performing lateral ankle stabilization techniques, ultrasound-guided arthroscopy can make the direct visualization of ankle anatomical landmarks and structures possible and can also effectively reduce surgical time and decrease the incidence of iatrogenic damage to neurovascular and other soft-tissue structures [39]. Similarly, Yang et al. conducted a randomized controlled study in which ultrasound-mediated anaesthesia was used in 38 patients who needed surgery on the ankle joint and not used in another 38; they found that the use of ultrasound resulted in fewer complications, which suggests a direction for future research.

In the epidemiology cluster (cluster 3), keywords such as female and male appeared more recently. Therefore, epidemiological factors such as sex and age have gradually drawn attention in a large number of clinical studies, and sex is one of the important factors influencing the diagnostic models and prognostic models of some diseases. For example, in a study of combined ultrasound and nerve stimulator-guided deep nerve block, the research subjects were also grouped by sex [40]. Similarly, in a study of risk factors for osteoporosis and associated fractures, female sex has long been listed as a risk factor, and the secretion of female oestrogen has also become a point of consideration in the treatment of osteoporosis patients [41].

As shown in **Figure 7**, the words that remained important for the longest were bone and articular cartilage, and the newest important keywords were instability and fracture. Therefore, we speculated that the study of bone joints would increase in the future. Over the last two decades, a number of technical advances have improved the ultrasound imaging of joints and soft tissues, increasing the accuracy of joint disease assessment [42]. For example, the ultrasound detection of synovial effusion and synovial hypertrophy in knees has obtained good results [43, 44].

Clinical research addresses the diagnosis, treatment, prognostic prediction, and prevention of diseases. Ultrasound is a useful tool in clinical practice, and research results can be quickly converted to clinical applications. Clinical randomized controlled trials provide highly reliable evidence that can be translated into clinical practice. We searched Clinicaltrials.gov and found 7 documented clinical randomized controlled trials (**Table 5**). Ultrasound-guided knee injections, as a focus in research on bones and joints, were also the focus of clinical randomized controlled trials, which is similar to the results shown in **Figure 7**. Surprisingly, most of the clinical studies were related to nerve blocks performed under ultrasound guidance, which were found to achieve good therapeutic effects, providing a new direction for the application of ultrasound in treatment. Since all 7 clinical trials were therapeutic, it is reasonable to believe that ultrasound, as a traditional diagnostic tool, is increasingly being used as a treatment.

This bibliometric analysis investigated the publications that were extracted from the WOS database. While attempting to ensure the data were objective and reliable, limitations were inevitable. According to our inclusion criteria, only English-language publications were collected, and some important studies not published in English may have been missed. In addition, the database is still constantly being updated and the exclusion of non-research articles may interfere with the results of the study, our results may differ slightly from the actual results. As for the evaluation index of articles, we only used the average number of citations, while the median and IQR may bring different results, which is worth of further discussion. In terms of the number of published articles, in

Table 5. Seven documented RCT clinical trials related to the use of ultrasound in orthopaedics

Study	Study title	Country	Design	No. of patients	Conditions	Intervention		Primary outcome measurement	Primary purpose	Summary
						Treatment group	Comparison group			
1	Intense Therapeutic Ultrasound - Treatment for Chronic Plantar Fascia Musculoskeletal Pain Reduction	United States	Randomized, Parallel Assignment, Masking: Single (Investigator)	41	Chronic Plantar Fasciitis	Intense Therapeutic Ultrasound Treatment for Chronic Plantar Fasciitis	ShamIntense Therapeutic Ultrasound Treatment for Chronic Plantar Fasciitis	Average Percentage of Change as Reported Using Foot Function Index Pain Subscale	Treatment	Double-blinded feasibility study of the treatment of pain related to chronic plantar fasciitis. A total 37 patients (27 treated and 12 control/sham treated) received 2 treatments, 2 weeks apart on subcutaneous plantar fascia musculoskeletal tissue along with Standard of Care treatments as prescribed by the Principal Investigator.
2	Ultrasound Guided Distal Sciatic Nerve Block - a Comparison With Nerve Stimulator Technique	No	Randomized, Parallel Assignment, Masking: None (Open Label)	250	Other Surgical Procedures	Ultrasound-guided block	Nerve stimulation technique	Success Rate Without Supplementation	Treatment	Performed in patients undergoing distal sciatic nerve block, this prospective, randomized trial compared it with ultrasound-guided distal subepineural block. The hypothesis was that intraepineural injection of local anaesthetic using nerve stimulation technique is common and associated with a high success rate.
3	Multicentre Continuous Peripheral Nerve Block Surveillance Study	United States	Randomized, Parallel Assignment, Masking: None (Open Label)	1821	Postoperative Pain	ultrasound imaging-guided peripheral nerve block	Stimulator guided nerve block	Complications of Peripheral Nerve Block	Treatment	This two-tiered study was a multi-centre, open-label, surveillance study of the use of continuous nerve blocks with the ON-Q® C-bloc and either nerve stimulator or ultrasound-guided continuous nerve block techniques. This study was developed to investigate specific aspects of complication rates related to continuous nerve block techniques in patients undergoing orthopaedic surgical procedures.
4	Ultrasound Guided Knee Injections in Musculoskeletal Medicine	United States	Randomized, Parallel Assignment, Masking: Double (Participant, Outcomes Assessor)	63	Knee Osteoarthritis	1. Joint line ultrasound 2. Joint line landmark 3. Suprapatellar ultrasound 4. guided Suprapatellar Landmark	NO	Number of Participants With Successful Knee Injection	Treatment	This study compared the accuracy and patient-reported outcomes between four different techniques used to perform a knee injection.
5	Ropivacaine Block Alone or With Perineural or Systemic Dexamethasone for Pain in Shoulder Surgery	United States	Randomized, Parallel Assignment, Masking: Quadruple (Participant, Care Provider, Investigator, Outcomes Assessor)	130	Shoulder Injury	1. Dexamethasone Block 2. Dexamethasone IV	Placebo	Duration of Sensory Blockade	Supportive Care	This study was a prospective, randomized, double-blind, controlled study to compare pain block with (1) ropivacaine and saline plus intravenous saline vs (2) ropivacaine and dexamethasone plus intravenous saline vs (3) ropivacaine and saline plus intravenous dexamethasone. Patients were recruited sequentially and assigned to the three groups at random in equal ratios.

6	Computer Assisted Instrument Guidance (CAIG) for Orthopaedic Peripheral Nerve Blocks	The United States	Randomized, Parallel Assignment, Masking: Single (Outcomes Assessor)	27	Peripheral Nerve Blocks	Peripheral Nerve Block With Computer-Assisted Instrument Guidance	Peripheral Nerve Block Without Computer-Assisted Instrument Guidance	Time Needed to Correctly Identify the Neural Structure(s) and Induce the Peripheral Nerve Block	Supportive Care	The objective of this research was to determine if the addition of the Clear Guide ONE, a Computer-Assisted Instrument Guidance (CAIG) system, provides improvement over existing ultrasound-guided, needle-based procedures for peripheral nerve blocks. Ultrasound can visualize the targeted vessel or nerve, but the addition of the CAIG may help the clinician better guide the needle to the target.
7	Analgesic Efficacy of Interscalene Nerve Block Versus Local Infiltration Analgesia Following Total Shoulder Arthroplasty	United States	Randomized, Parallel Assignment, Masking: Single (Investigator)	125	Pain, Postoperative	1. Single-Shot Interscalene Nerve Block 2. Continuous Interscalene Nerve Block 3. Local Infiltration Analgesia	No	Comparing Pain Intensity and Opioid-Related Adverse Effects Using Overall Benefit of Analgesia Score	Treatment	The Investigators planned to assess and compare analgesia outcomes between three intervention groups: single shot interscalene brachial plexus block (SISB), continuous interscalene brachial plexus block (CISB), and local infiltration analgesia (LIA).

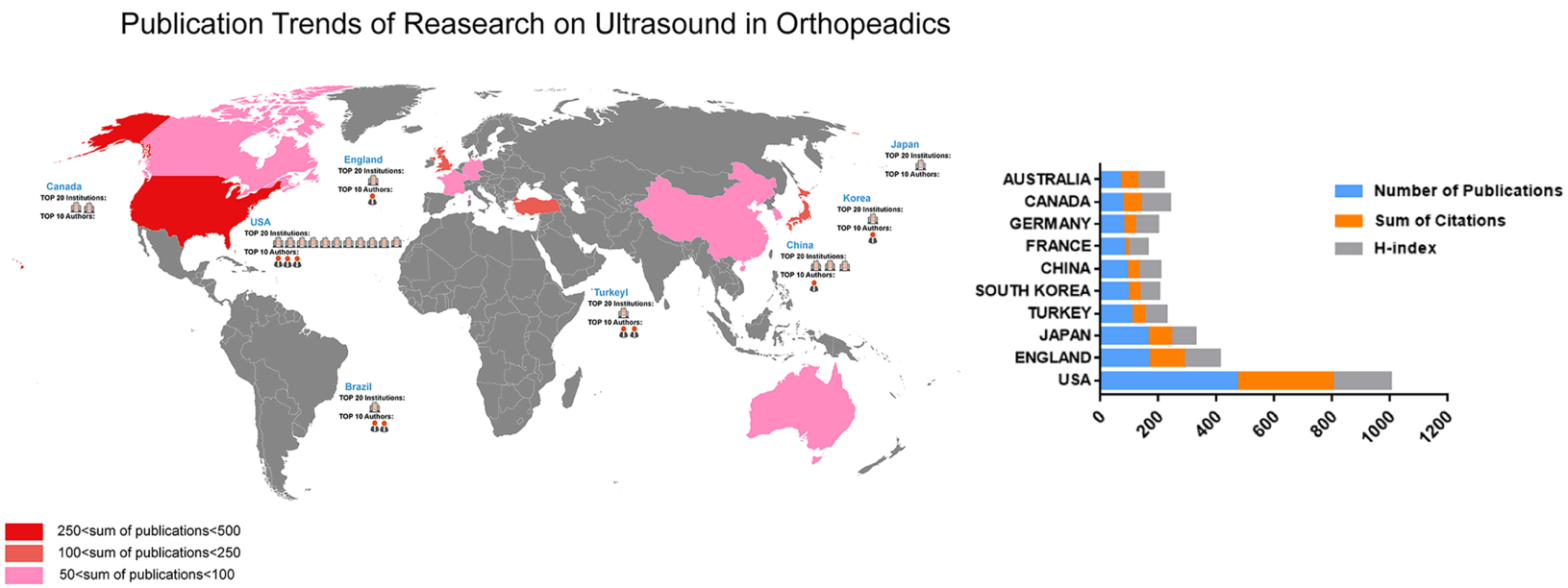

Figure 8. Publication trends in research on the use of ultrasound in orthopaedics. (The materials came from https://freevectormaps.com/).

addition to GDP, the impact of other cultural, social and scientific factors on research is also worth of study. In terms of the type of article, the original studies and the reviews need to be further compared. For more comprehensive results, database such as Medline, Scopus or Google Scholar could be adopted and compared in further study.

Conclusions

The United States was the most productive country with regard to research on the use of ultrasound in orthopaedics, and we predict that China will surpass the United States in publications over the next two decades. The keywords gradually shifted from treatment to diagnosis and epidemiology. Promising research hotspots, such as MRI, complications and sex, should be the focus of future research. Although the current amount of research is inadequate, we believe that growth in the future will be rapid. Our study provides profound insights into the history and current status of research on the use of ultrasound in orthopaedics, which may indicate the future trends (**Figure 8**).

Disclosure of conflict of interest

None.

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Supplementary Table 1. The analytic consequence of 66 keywords with at least 62 occurrence times

No.	Label	Cluster	Links	Occurrences	Average appearing years (AAY)	Average citations
1	accuracy	1	1104	161	2015.1491	12.0621
2	area	3	1363	189	2015.3016	11.6825
3	article	1	581	90	2015.2444	14.7
4	association	3	687	94	2015.7553	13.2021
5	baseline	2	712	76	2015.2632	16.6711
6	case	1	2207	337	2014.9377	9.7596
7	change	3	2081	285	2015.0456	13.2596
8	child	1	527	76	2014.8158	7.3816
9	complication	2	956	138	2015.3768	9.5362
10	control	3	1044	144	2014.3056	13.4444
11	control group	2	837	105	2015.3048	10.6
12	correlation	3	1390	197	2015.5178	10.5685
13	degree	3	1211	168	2015.3929	12.4464
14	detection	1	707	97	2014.433	11.8144
15	developmental dysplasia	1	537	73	2014.7534	7.6986
16	diagnosis	1	2389	338	2015.1065	11.9172
17	effect	2	1894	264	2014.697	14.3447
18	effectiveness	2	825	93	2015.043	14.0538
19	efficacy	2	905	109	2015.1927	13.1651
20	examination	1	2307	330	2014.797	14.4758
21	female	3	917	114	2015.6667	10.0439
22	fracture	1	925	134	2014.9776	9.2761
23	function	2	1199	146	2015.2466	15.9932
24	group	2	3295	440	2014.9136	14.0159
25	hip	1	1069	154	2014.987	10.1883
26	image	3	1325	189	2014.9947	13.6667
27	imaging	1	1039	151	2015.0993	13.5497
28	improvement	2	1335	143	2014.9021	15.8741
29	incidence	1	550	81	2014.8148	11.9136
30	injection	2	1256	158	2015.2722	15.2468
31	intervention	2	1155	132	2014.8939	13.1136
32	lesion	1	843	121	2014.9174	10.4298
33	literature	1	815	114	2015.0614	14.0526
34	low intensity	2	387	62	2014	14.5968
35	magnetic resonance imaging	1	1183	159	2015.7107	12
36	male	3	909	114	2015.8596	10.5351
37	man	3	728	92	2014.6413	10.6739
38	management	2	1054	138	2015.2391	12.558
39	measurement	3	2096	302	2014.9536	12.8146
40	month	2	2591	318	2015.1415	14.5503
41	mri	1	1389	181	2015.5635	11.9171
42	muscle	3	1321	184	2015.25	12.7174
43	pain	2	3166	391	2015.1611	14.5243
44	participant	3	1156	147	2015.2857	12.2313
45	position	3	914	137	2015.2482	8.9781
46	presence	1	942	125	2015.056	12.344

47	prevalence	3	516	72	2014.7778	18.6667
48	procedure	2	1293	191	2015.1466	10.4712
49	radiograph	1	825	114	2015.2018	10.7456
50	reduction	2	826	102	2014.8922	11.5098
51	relationship	3	892	126	2015.2619	12.6508
52	reliability	3	936	131	2015.4351	11.8855
53	review	1	1114	153	2015.183	14.9869
54	role	1	740	108	2014.6759	16.037
55	score	2	2562	316	2015.2215	16.8987
56	sensitivity	1	1276	163	2015.411	13.7914
57	significant difference	2	1756	225	2015.1733	12.4311
58	specificity	1	1130	143	2015.2308	14.042
59	subject	3	1178	169	2014.3314	14.9527
60	thickness	3	1661	215	2014.7535	15.7256
61	treatment	2	3552	459	2015.098	11.5447
62	ultrasound imaging	3	767	105	2015.0857	15.6
63	value	1	2006	270	2015.1926	13.8148
64	week	2	2004	239	2014.8787	11.3347
65	woman	3	802	96	2014.6146	10.7812
66	wrist	1	584	86	2015.4535	11.7209