



# Global Research Status and Frontier Analysis of Clavicle Fractures

Yao Liu<sup>1,2</sup>, Zhaoji Li<sup>1,2</sup>, Zhe Song<sup>2</sup>

<sup>1</sup>Yan'an Medical College, Yan'an University, Yan'an 716000, Shaanxi, China

<sup>2</sup>Department of Orthopaedic Trauma, Xi'an Honghui Hospital, Xi'an Jiaotong University College of Medicine, Xi'an 710054, Shaanxi, China

**Abstract:** ***Objective:** This study employs bibliometric to systematically analyze research dynamics in the field of clavicle fracture from 1996 to 2024, thereby revealing knowledge evolution and development trends. **Methods:** Based on the Web of Science Core Collection database, 1592 articles were analyzed by Excel and VOSviewer, covering the annual publication, national or regional contribution, institutional cooperation network, author contribution, journal influence and keyword co-occurrence mapping. **Results:** Global research has shown fluctuating growth. The United States led the world in terms of publication volume, citation frequency and H-index. Institutional analysis showed that the University of California System in the United States had the highest number of publications, while the University of Toronto in Canada was the most academically influential institution with the first-ranked citation frequency and H-index. In terms of individual contributions, Houwert RM from the Netherlands and McKee MD from Canada were the most productive and highly cited respectively, and Journal of Shoulder and Elbow Surgery was ranked first in terms of the number of articles, frequency of citations, and H-index of core journals. Keyword analysis showed that the research hotspots focused on bone nonunion, plate fixation and biomechanics; keywords such as locking plate, midshaft clavicle fracture, coracoclavicular stabilization, ultrasound and acromioclavicular joint dislocation have become the emerging trends of research in recent years. **Conclusion:** This research demonstrates a multidisciplinary cross-disciplinary trend, and technological innovation of internal fixation and precise minimally invasive treatment constitute dual core of future research. Visualization analysis offers evidence-based support for clinical decision and research planning.*

**Keywords:** Clavicle, Fracture, Bibliometrics, VOSviewer.

## 1. Introduction

The clavicle, an S-shaped bone that connects the pectoral girdle to the thorax, possesses unique biomechanical characteristics that make it prone to traumatic fractures [1]. Around 80% of clavicle fractures typically occur in the midshaft region [2], which is attributed to a significant decrease in cortical bone thickness, leading to stress concentration at this specific anatomical site [3]. High-energy impacts and sports-related injuries are commonly identified as primary causes. Diagnostic evaluation usually commences with X-rays for initial screening and postoperative monitoring [4], while computed tomography (CT) scans with 3D reconstruction are employed for detailed preoperative planning in complex cases [5]. Recent evidence suggests that traditional conservative treatments may result in higher rates of malunion and nonunion than previously believed [6], prompting a shift towards surgical interventions in clinical practice [7]. Various fixation techniques, such as intramedullary nails, locking plates, and hook plates, exhibit considerable anatomical diversity. Nonunion, the most severe

complication, arises from a combination of biological and mechanical factors [8]. This study utilizes bibliometric analysis to systematically assess 1,592 publications on clavicular fractures spanning three decades. By quantitatively mapping spatiotemporal distribution patterns, knowledge network structures, and research focal areas, our objective is to delineate evolutionary trends, identify central research clusters, and highlight emerging frontiers. The resulting evidence framework offers clinicians and researchers a data-driven basis for optimizing therapeutic strategies and prioritizing scientific inquiries [9].

## **2. Materials and Methods**

### **2.1 Literature Search**

The literature search was conducted in the Web of Science Core Collection (WoSCC) database as of December 31, 2024, with the search query TS= ("clavicle fracture\*") OR TS= ("fracture\*", "clavicle") OR TS= ("Fracture\* of the Clavicle"). The initial screening retrieved 1,870 potentially relevant articles.

### **2.2 Inclusion and Exclusion Criteria**

Inclusion Criteria: (1) English research articles or reviews published from January 1, 1996 to December 31, 2024. (2) Literature that explicitly focuses on studies of clavicle fractures. Exclusion criteria: (1) Non-research literature like conference records, editorials, comments, and letters. (2) Irrelevant or duplicate articles.

After rigorous screening based on the inclusion and exclusion criteria, 1,592 articles were retained for analysis.

### **2.3 Data Visualization and Bibliometric Analysis**

The following core information was extracted from the included literature: (1) Literature characteristics: title, author, year of publication, journal and its impact factor; (2) Regional attributes: country, region and institution; (3) Indicators of academic influence: citation frequency and H-index; (4) Content attributes: keywords and references. The full records and references were also exported as plain text files.

Microsoft Excel performed descriptive statistics to quantify research trends, while VOSviewer (v1.6.20) generated visualizations of collaboration networks and keyword co-occurrence clusters.

## **3. Result**

### **3.1 Annual Publication Trend Analysis**

Global clavicular fracture research exhibited fluctuating growth from 1996 to 2024 (Figure 1). Notably, 42.1% of total publications concentrated in the most recent five-year period. The number of publications reached a peak of 149 in 2022. Based on the predicted trend model equation  $y=0.1828x^2-0.4805x+8.1735$  ( $R^2=0.925$ ), the number of publications on clavicle fractures is expected to exceed 158 by 2030.

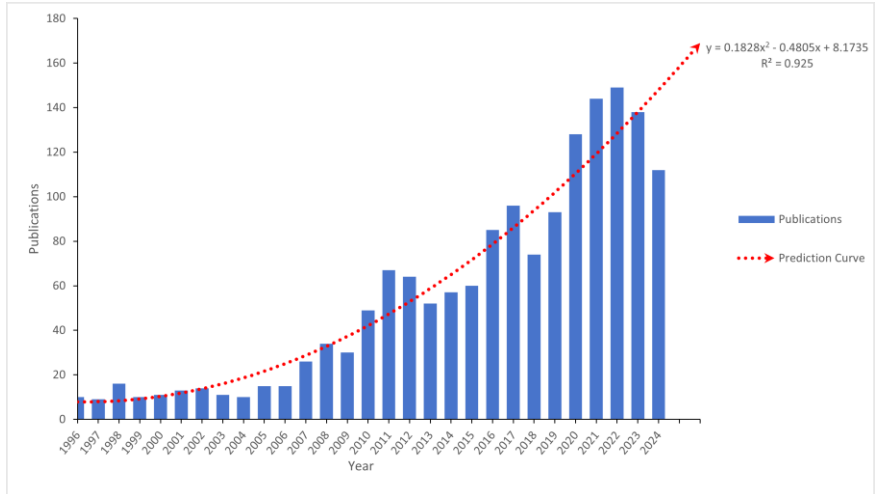


Figure 1: Annual Publication Volume and Trend Forecast Model Chart

### 3.2 National Contributions

Researchers from 77 countries across the world have contributed to the research. Among them, 28 countries have published 10 or more articles (Table 1). The United States (493, 30.97%), China (237, 14.89%), and Germany (97, 6.09%) together account for over half of the global academic output.

Table 1: Ranking of Top 10 Countries by Publication Volume

Rank	Country	Total Publications	Total Citations	H-index	Total Link Strength
1	USA	493	11415	54	122
2	PEOPLES R CHINA	237	2064	19	16
3	GERMANY	97	1693	23	83
4	ENGLAND	89	2175	23	62
5	NETHERLANDS	77	2260	27	68
6	SOUTH KOREA	71	1109	18	3
7	CANADA	64	3233	23	63
8	SWITZERLAND	59	1383	17	58
9	AUSTRALIA	56	1033	18	44
10	TURKEY	49	408	12	4

The country collaboration network diagram revealed the US as the central hub (Total Link Strength, TLS=122), its collaboration intensity with Canada reaches 23. Although China ranks second in the world in terms of the productivity, its TLS of 16 significantly trailed European and North American counterparts (Figure 2).

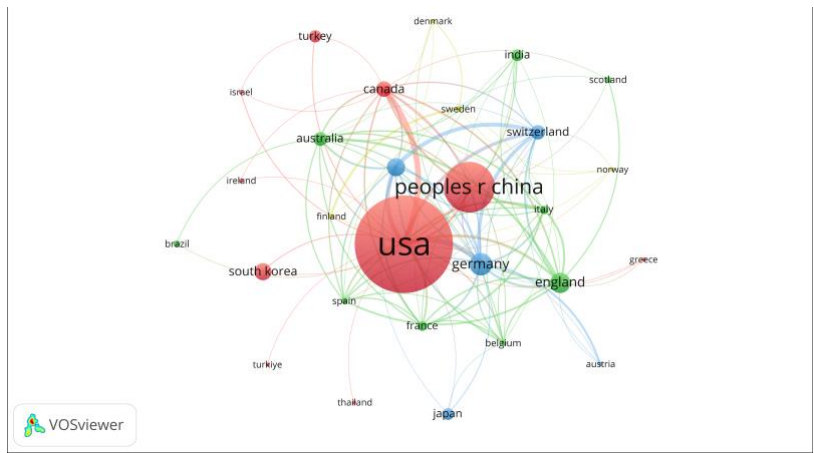


Figure 2: Country Cooperation Network Map

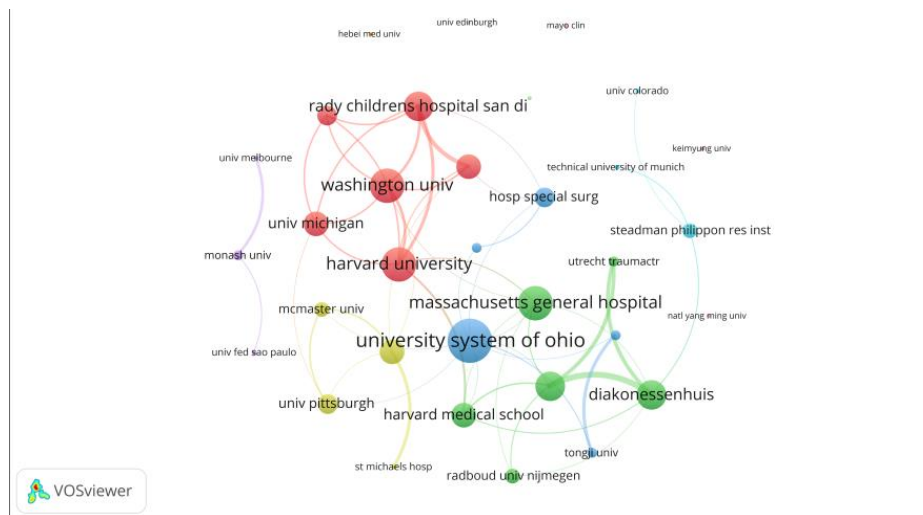
### 3.3 Institutional Productivity and Collaboration Analysis

Five of the 2,048 participating institutions globally involved in this field have more than 20 publications (Table 2). The *University of California System* (42 articles) and *Harvard University* (41 articles) led in productivity, while the *University of Toronto* in Canada is the most academically influential institution with 2,487 citations and an H-index of 17.

**Table 2: Ranking of Institutions by Top 10 Publication Volume**

Rank	Institutions	Total Publications	Total Citations	H-index	Country
1	University of California System	42	730	14	USA
2	Harvard University	41	1126	16	USA
3	University of Toronto	30	2487	17	CANADA
4	Utrecht University	26	898	15	NETHERLANDS
5	University System of Ohio	21	347	9	USA
6	Diakonessenhuis	20	884	14	NETHERLANDS
7	Harvard Medical School	18	610	9	USA
8	Massachusetts General Hospital	18	738	11	USA
9	Rady Childrens Hospital San Diego	18	477	9	USA
10	Technical University of Munich	18	293	9	GERMANY

Institutional collaboration mapping (Figure 3) identified the University System of Ohio as the most interconnected node (Links = 9), reflecting extensive research partnerships.



**Figure 3: Institution Collaboration Network Map**

### 3.4 Author Analysis

Among the 6,474 global scholars in this field, 13 have published over 10 articles (Table 3). Professor Houwert RM from the Netherlands leads with 23 publications on minimally invasive fixation techniques for clavicle fractures. In terms of academic impact, Canadian scholar McKee MD tops the list in nonunion research with 2,140 total citations and 118.89 citations per article on average.

**Table 3: Ranking of authors by Top 10 Publication Volume**

Rank	Authors	Total Publications	Total Citations	Citation per Paper	H-index	Country
1	Houwert RM	23	974	42.35	15	NETHERLANDS
2	Mckee MD	18	2140	118.89	13	CANADA
3	Beeres FJP	13	209	16.08	8	SWITZERLAND
4	Robinson CM	13	1239	95.31	9	ENGLAND
5	Van Heijl M	12	509	42.42	8	NETHERLANDS
6	Kirchhoff C	11	94	8.55	6	GERMANY

7	Li L	11	47	4.27	4	PEOPLES R CHINA
8	Millett PJ	11	797	72.45	10	USA
9	Pennock AT	11	145	13.18	7	USA
10	Schemitsch EH	11	992	90.18	10	ENGLAND

Co-authorship networks among prolific authors who have published at least 5 publications revealed three distinct clusters (Figure 4): The largest cluster centered on Houwert RM, Beeres FJP, and Van Heijl M demonstrated both high productivity and tight collaboration. In addition, Two independent groups led by McKee MD and Pennock AT represented specialized research lineages.

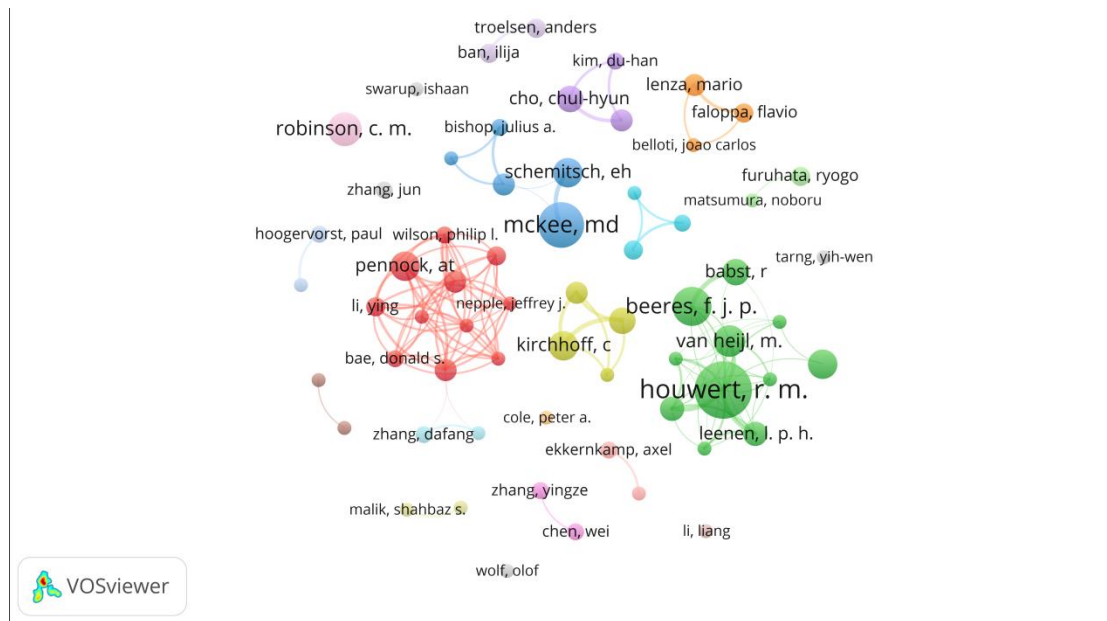


Figure 4: Author Collaboration Network Map

### 3.5 Journal Distribution

The *Journal of Shoulder and Elbow Surgery* maintained a dominant position by a substantial margin among the top 10 journals ranked by publication volume (Table 4). Notably, the *American Journal of Sports Medicine* led in average citations per article (46.93) and recent impact factor (5.605) despite ranking tenth in publication count.

Table 4: Ranking of Top 10 Journals by Publication Volume

Rank	Journal	Total Publications	Total Citations	H-index	JCR Quartiles	Impact Factor
1	Journal of Shoulder and Elbow Surgery	103	3497	31	Q1	3.049
2	Journal of Orthopaedic Trauma	86	2551	24	Q3	2.239
3	Injury-International Journal of the Care of the Injured	83	1530	24	Q2	2.416
4	Archives of Orthopaedic and Trauma Surgery	50	1280	21	Q2	2.463
5	Orthopedics	47	593	15	Q3	1.269
6	BMC Musculoskeletal Disorders	45	341	10	Q2	2.259
7	Cureus Journal of Medical Science	34	42	4	Q3	1.1
8	European Journal of Trauma and Emergency Surgery	28	260	8	Q2	2.441
9	International Orthopaedics	28	743	17	Q2	2.822
10	American Journal of Sports Medicine	27	1267	19	Q1	5.605

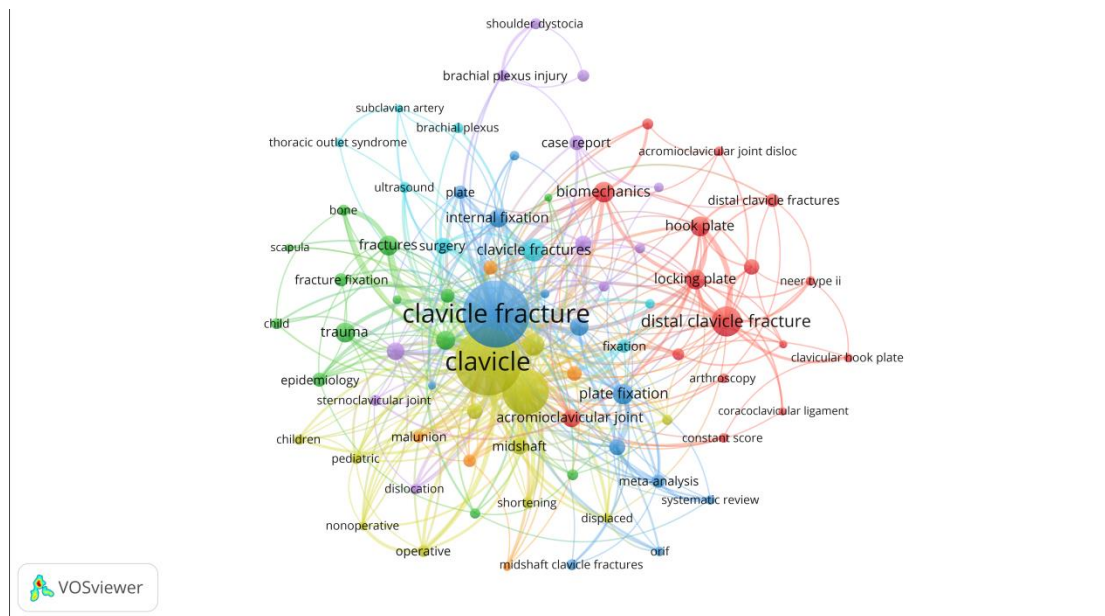
### 3.6 Keyword Analysis.

After excluding the search terms from the 2,496 keywords, Table 5 lists the top 10 keywords by frequency. The top three are "nonunion" (49 times), "plate fixation" (44 times), and "biomechanics" (43 times).

**Table 5:** Ranking of Top 10 Keywords by Frequency of Appearance

Rank	Keywords	Frequency	Total Link Strength
1	nonunion	49	238
2	plate fixation	44	191
3	Biomechanics	43	197
4	Trauma	41	171
5	hook plate	40	155
6	locking plate	40	167
7	Shoulder	39	178
8	internal fixation	36	165
9	acromioclavicular joint	34	148
10	adolescent	33	162

Co-occurrence and cluster analysis was performed on 78 keywords with frequencies exceeding 10, revealing 7 distinct research clusters through hierarchical clustering (Figure 5). Specifically, the clustering analysis delineated seven thematic groups: Red Cluster 1: Distal clavicle fracture diagnosis and treatment. Green Cluster 2: Epidemiology and biomechanical risk factors. Dark Blue Cluster 3: Mid-clavicle fracture treatment. Yellow Cluster 4: Pediatric clavicle fracture management. Purple Cluster 5: Post-operative complication management for fractures. Light Blue Cluster 6: Neurovascular complications of clavicle fractures. Orange Cluster 7: Complications after plate osteosynthesis.



**Figure 5:** Keyword Co-occurrence and Clustering Network Visualization

In the keyword temporal overlay visualization (Figure 6), emerging research hotspots in recent years are represented by yellow nodes for keywords such as "open reduction and internal fixation," "conservative treatment," "locking plate," "midshaft clavicle fracture," "coracoclavicular stabilization," "ultrasound," and "acromioclavicular joint dislocation."

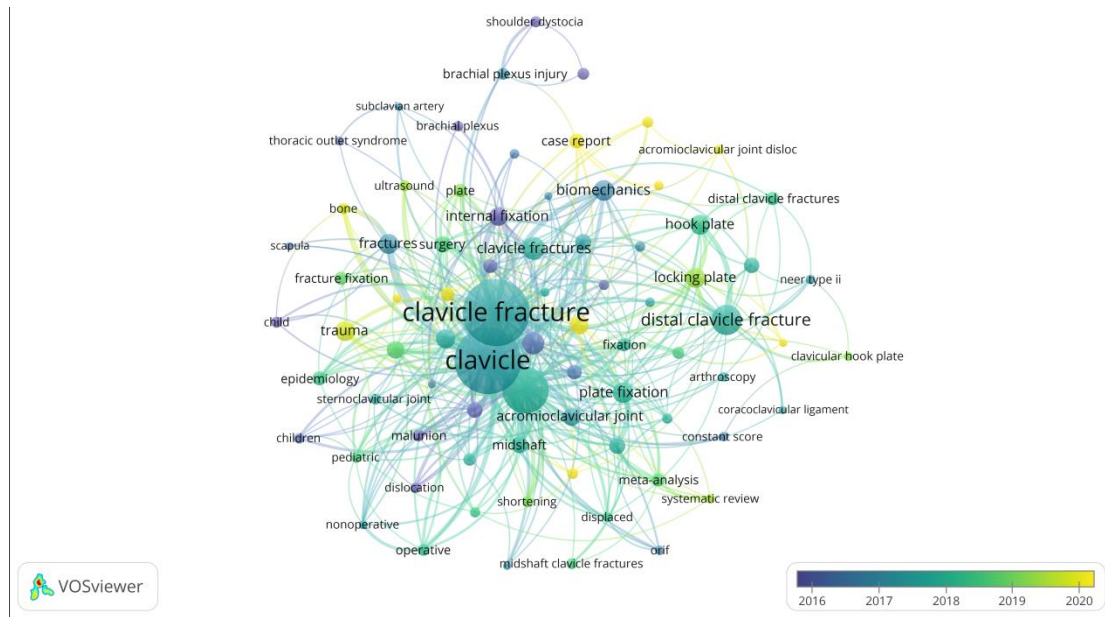


Figure 6: Temporal Overlay Network of Keywords

## 4. Discussion

### 4.1 Research Hotspots

Cluster analysis of high-frequency keyword co-occurrence networks, specifically Green Cluster 2, reveals intricate associations among "biomechanics," "trauma," "shoulder complex," "acromioclavicular joint," and "adolescent population," collectively elucidating the core pathomechanisms. The transition zone between the medial and lateral curvatures in midshaft S-shaped clavicles serves as an inherent stress concentration site due to abrupt geometric changes, indicating susceptibility to fractures under average axial compressive loads of 1526 N [10-11]. Existing clinical evidence identifies direct shoulder trauma as the primary cause of clavicular fractures [12], with biomechanical studies confirming substantial correlations between force transmission patterns and mechanisms for stabilizing the acromioclavicular joint [13]. Notably, adolescents demonstrate distinct epidemiological characteristics characterized by heightened bone remodeling processes and increased incidence of sports-related injuries [14].

The frequent use of terms such as "plate fixation," "hook plate," "locking plate," and "internal fixation" underscores the key research aspects within internal fixation techniques. Plate fixation plays a crucial role in restoring clavicular biomechanical stability by reconstructing anatomical length and correcting alignment, leading to a notable reduction in nonunion rates [15]. Hook plate systems incorporate a transcoracoid hook design that leverages mechanical principles to enhance stability in the clavicular-coracoid complex and counteract vertical shear forces on the distal fracture fragment [16]. Locking plates, utilizing angular-stable screw fixation in conjunction with three-point fixation systems, establish robust support structures that offer significant advantages in withstanding bending and compressive stresses [17].

Cluster 7, focused on "nonunion," presents a well-established evidence-based framework for implementing multidimensional therapeutic approaches. While extracorporeal shock wave therapy (ESSWT) has shown promise in upregulating vascular endothelial growth factor expression via mechanotransduction pathways, its clinical effectiveness remains limited [18]. Conversely, anatomical locking plates with interfragmentary dynamization have demonstrated a success rate of 87.3% in

achieving osseous union in challenging cases by promoting callus formation through controlled micromotion [19]. The combination of autogenous iliac crest graft and plate fixation is considered the standard approach for nonunion reconstruction due to its dual osteoinductive and osteoconductive properties [20]. Vascularized bone grafting presents a viable option for treating refractory nonunions by restoring local microcirculation [21]. The Induced Membrane Technique utilizing beta-tricalcium phosphate has recently emerged as a promising method for addressing bone defects [22].

#### **4.2 Trends in Clavicle Fracture Research.**

The analysis of the temporal overlay map using the keyword "temporal overlay map" indicates a shift towards precision interventions in the treatment of clavicular fractures. Specifically, terms such as "conservative treatment," "open reduction and internal fixation," "locking plate," and "midshaft clavicle fracture" are highlighted in yellow nodes, reflecting this paradigm shift. Additionally, attention has been focused on "coracoclavicular stabilization," "ultrasound," and "acromioclavicular joint dislocation."

The debate between conservative management and open reduction and internal fixation in clavicular fracture treatment persists [23]. However, contemporary evidence suggests a transition from traditional conservative approaches to more precise interventions [24]. The utilization of biomechanically optimized locking plates not only improves stabilization of midshaft fractures but also preserves subacromial space integrity during distal fracture fixation. This results in superior Constant-Murley scores and reduced rates of implant irritation [25-26].

Advancements have been made in the management of acromioclavicular joint dislocations with concurrent distal clavicular fractures. Arthroscopically assisted coracoclavicular stabilization offers anatomical reduction through minimally invasive techniques, addressing drawbacks associated with traditional open reduction and internal fixation such as implant mismatch and the need for secondary removal procedures [27]. Despite potential radiographic distal clavicle malunion, maintaining healing of the coracoclavicular ligament and proper articular congruence ensures unaffected clinical outcomes [28].

Ultrasonography serves a dual purpose in clinical practice. As a diagnostic tool, it demonstrates high sensitivity and specificity exceeding 90% in detecting pediatric clavicular fractures [29-30]. Therapeutically, Low-intensity pulsed ultrasound (LIPUS) modulates bone metabolism by upregulating osteocalcin expression and enhancing callus mineralization density in cases of delayed unions [31]. This combined diagnostic and therapeutic strategy suggests that noninvasive interventions have the potential to redefine future treatment protocols.

#### **4.3 Future Research Prospects**

The advancement of intelligent orthopedic technologies has ushered in a new era of innovative breakthroughs in the management of clavicular fractures. Deep learning-based surgical planning systems show promise in optimizing personalized plate pre-bending and screw insertion angles using CT-based anatomical reconstructions [32]. These systems also allow for real-time assessment of callus growth when combined with ultrasound imaging [33].

This highlights the importance of international research collaborations to establish multinational consortia for evidence-based medical practices through standardized data sharing. Additionally, investigating the efficacy of biological therapies such as platelet-rich plasma (PRP) [34], bone morphogenetic proteins (BMP) [35], and microRNAs [36] through large-scale randomized controlled

trials is crucial for clinical translation. Intelligent rehabilitation assessment systems that combine biomechanical parameters with patient feedback will enhance personalized rehabilitation protocols, leading to a comprehensive management approach encompassing precision treatment, dynamic evaluation, and functional rehabilitation.

#### **4.4 Limitations**

This study acknowledges two main limitations. Relying solely on English-language data from Web of Science precludes access to multidisciplinary databases such as PubMed and Scopus, as well as Chinese research in CNKI, leading to an incomplete portrayal of domestic research. To bolster the robustness of evidence synthesis, forthcoming studies should integrate cross-linguistic literature retrieval methods and develop culturally inclusive assessment frameworks.

### **5. Conclusion**

This study conducted an analysis of clavicle fracture research spanning the years 1996 to 2024, delineating the current landscape and prospective developments. The United States exhibits quantitative preeminence in terms of overall publications, citations, and H-index. Conversely, qualitative indicators unveil Canadian prominence, with the University of Toronto attaining the highest aggregate citations and H-index, surpassing the publication prowess of the University of California System. Collaborative efforts spanning multiple nations, spearheaded by Dutch researcher Houwert RM and Canadian investigator McKee MD, have notably propelled crucial research domains, particularly in the refinement of biomechanical modeling and updates to evidence-based treatment guidelines. *The Journal of Shoulder and Elbow Surgery* emerges as the foremost scholarly outlet, upholding the highest citation rate and disciplinary H-index. Current research endeavors are centered on nonunion, plate fixation, and biomechanical aspects. Emerging data hints at forthcoming shifts in paradigms towards the utilization of locking plates, midshaft clavicle fractures, coracoclavicular stabilization, ultrasound applications, acromioclavicular joint dislocation, conservative treatment modalities, and open reduction and internal fixation techniques.

### **References**

- [1] Hyland S, Charlick M, Varacallo M A. Anatomy, Shoulder and Upper Limb, Clavicle[J]. 2025.
- [2] Ramponi D R, Jo C M. Clavicle Fractures[J]. *Adv Emerg Nurs J*, 2021, 43(2): 123-127.
- [3] Li Z, Kindig M W, Kerrigan J R, et al. Development and validation of a subject-specific finite element model of a human clavicle[J]. *Comput Methods Biomech Biomed Engin*, 2013, 16(8): 819-829.
- [4] Kani K K. Clavicle Fractures: Review and Update for Radiologists[J]. *Curr Probl Diagn Radiol*, 2020, 49(3): 199-204.
- [5] Van Tongel A, De Wilde L, Shimamura Y, et al. Fracture patterns in midshaft clavicle fractures[J]. *Acta Orthop Belg*, 2021, 87(3): 501-507.
- [6] von Ruden C, Rehme-Rohrl J, Augat P, et al. Evidence on treatment of clavicle fractures[J]. *Injury*, 2023, 54 Suppl 5: 110818.
- [7] Frima H, van Heijl M, Michelitsch C, et al. Clavicle fractures in adults; current concepts[J]. *Eur J Trauma Emerg Surg*, 2020, 46(3): 519-529.
- [8] Nicholson J A, Makaram N, Simpson A, et al. Fracture nonunion in long bones: A literature review of risk factors and surgical management[J]. *Injury*, 2021, 52 Suppl 2: S3-S11.
- [9] Ninkov A, Frank J R, Maggio L A. Bibliometrics: Methods for studying academic publishing[J]. *Perspect Med Educ*, 2022, 11(3): 173-176.

- [10] Harnroongroj T, Tantikul C, Keatkor S. The clavicular fracture: a biomechanical study of the mechanism of clavicular fracture and modes of the fracture[J]. *J Med Assoc Thai*, 2000, 83(6): 663-667.
- [11] Kemper A, Stitzel J, Gabler C, et al. Biomechanical response of the human clavicle subjected to dynamic bending[J]. *Biomed Sci Instrum*, 2006, 42: 231-236.
- [12] Defroda S F, Lemme N, Kleiner J, et al. Incidence and mechanism of injury of clavicle fractures in the NEISS database: Athletic and non athletic injuries[J]. *J Clin Orthop Trauma*, 2019, 10(5): 954-958.
- [13] Sachinis N P, Beitzel K. Risk for Fracture with Acromioclavicular Joint Reconstruction and Strategies for Mitigation[J]. *Clin Sports Med*, 2023, 42(4): 613-619.
- [14] Patel M, Heyworth B E, Dehghan N, et al. Clavicular Fractures in the Adolescent[J]. *J Bone Joint Surg Am*, 2023, 105(9): 713-723.
- [15] Baertl S, Alt V, Rupp M. Surgical enhancement of fracture healing - operative vs. nonoperative treatment[J]. *Injury*, 2021, 52 Suppl 2: S12-S17.
- [16] Sheth M M, Shybut T B. Operative Management for Displaced Distal Clavicle Fractures[J]. *Clin Sports Med*, 2023, 42(4): 695-711.
- [17] Uchiyama Y, Handa A, Omi H, et al. Locking versus nonlocking superior plate fixations for displaced midshaft clavicle fractures: A prospective randomized trial comparing clinical and radiographic results[J]. *J Orthop Sci*, 2021, 26(6): 1094-1099.
- [18] Jubel A, Knopf M, Jubel J M, et al. Clavicle nonunion[J]. *Unfallchirurgie (Heidelb)*, 2024, 127(11): 776-782.
- [19] Wiss D A, Garlich J M. Clavicle nonunion: plate and graft type do not affect healing rates-a single surgeon experience with 71 cases[J]. *J Shoulder Elbow Surg*, 2021, 30(3): 679-684.
- [20] Lim S, Cho E, Chun J M, et al. Osteosynthesis with autologous dual bone graft for nonunion of midshaft clavicle fractures: clinical and radiological outcomes[J]. *Eur J Orthop Surg Traumatol*, 2022, 32(1): 159-165.
- [21] Deng A D, Innocenti M, Arora R, et al. Vascularized Small-Bone Transfers for Fracture Nonunion and Bony Defects[J]. *Clin Plast Surg*, 2020, 47(4): 501-520.
- [22] Arakawa K, Watanabe Y, Sasaki G, et al. Induced membrane technique using beta-tricalcium phosphate for reconstruction of clavicle bone defect after fracture related infection - A case report[J]. *Trauma Case Rep*, 2024, 51: 101013.
- [23] Sax O C, Monarrez R, Bains S S, et al. Operative Versus Nonoperative Treatment for Closed Displaced Midshaft Clavicle Fractures[J]. *Hand (N Y)*, 2024, 19(2): 294-299.
- [24] Jeray K J, Broderick J S, Mullis B H, et al. Multicenter, Prospective, Observational Study of Nonoperative Versus Operative Treatment for High-Energy Midshaft Clavicle Fractures[J]. *J Orthop Trauma*, 2024, 38(7): 345-350.
- [25] Orlandi T V, Rogers N S, Burger M C, et al. A prospective randomized controlled trial comparing plating augmented with coracoclavicular fixation and hook plate fixation of displaced distal-third clavicle fractures[J]. *J Shoulder Elbow Surg*, 2022, 31(5): 906-913.
- [26] Elrih M, Quinlan J. Hook Plate Versus Distal Locking Plate for the Fixation of Unstable Distal Clavicle Injuries, Outcomes and Complications: A Meta-Analysis[J]. *Cureus*, 2022, 14(10): e30806.
- [27] Pieringer A, Welter J, Fischer J, et al. Complications following arthroscopic-assisted coracoclavicular stabilization in patients with unstable lateral clavicle fractures[J]. *Arch Orthop Trauma Surg*, 2023, 143(8): 4925-4931.
- [28] Degeorge B, Ravoyard S, Lazerges C, et al. Clinical Impact of Malunion After All-Arthroscopic Coracoclavicular Stabilization for Displaced and Unstable Lateral Clavicle Fractures[J]. *J Orthop Trauma*, 2022, 36(7): e271-e277.
- [29] Moritz J D. Sonographic Fracture Diagnosis in Children and Adolescents[J]. *Rofo*, 2023, 195(9): 790-796.

- [30] Galimberti L, Garbetta G, Poloniato A, et al. Ultrasound Diagnosis of Clavicle Fractures in Newborns: A Systematic Review[J]. *Children (Basel)*, 2024, 11(9).
- [31] Bhan K, Patel R, Hasan K, et al. Fracture Nonunions and Delayed Unions Treated With Low-Intensity Pulsed Ultrasound Therapy: A Clinical Series[J]. *Cureus*, 2021, 13(8): e17067.
- [32] Zheng Y, Zheng X G, Zhang J K, et al. Digital study on proximal clavicle anatomical plate based on 3D printing technology[J]. *Zhongguo Gu Shang*, 2024, 37(3): 278-280.
- [33] Zhang P, Li P, Liao S, et al. Fracture Nonunion Treated with Low-Intensity Pulsed Ultrasound and Monitored with Ultrasonography: A Feasibility Study[J]. *Biomed Res Int*, 2021, 2021: 8834795.
- [34] Borole A, Trubiano J, Viqueira M, et al. Intrinsic and Extrinsic Methods for Augmenting Fracture Healing in the Hand and Wrist[J]. *Cureus*, 2024, 16(12): e74972.
- [35] Kronenberg D, Brand M, Everding J, et al. Integrin alpha2beta1 deficiency enhances osteogenesis via BMP-2 signaling for accelerated fracture repair[J]. *Bone*, 2025, 190: 117318.
- [36] Hou X, Peng G, Zhao W, et al. Association of elevated exosomal miR-21 levels with nonunion in clavicular fractures post-ORIF: A prospective analysis[J]. *Injury*, 2024, 55(12): 111963.