Research Article

A bibliometric analysis of clinical research on fracture-related infection

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Background. Infection following orthopaedic trauma surgery is increasingly recognized as one of the major research priorities with as primary goal, improving patient care. This increased interest has been anecdotally recognized through published research, research grants, and, finally, with the development of the fracture-related infection (FRI) consensus group. In 2017, the accepted consensus definition of FRI was published, which has been followed by consensus recommendations from both a surgical and medical perspective. A bibliometric analysis was performed to objectively describe the trends in published clinical research related to FRI.

Methods. The terms related to FRI were searched in the Web of Science database between 2000 and 2020. The characteristics of clinical research on FRI regarding the author, country, journal, institution, scientific output, top 100 most cited articles, and trend topics were analyzed using Bibliometrix and WPS Office.

Results. A total of 2597 records were eligible for inclusion in this bibliometric approach, with studies originating from 89 countries, including eight languages. The United States of America (USA) published the highest number of articles and citations. International collaborations were present between 72 countries, with the most active country being the USA. The most contributive institution was the University of California. The highest number of papers and citations were from the Injury-International Journal of the Care of the Injured and the Journal of Orthopaedic Trauma. The top 100 most cited articles were published in 27 different journals, with the number of citations ranging between 97 and 1004. The latest trend topics were related to the diagnosis of FRI.

Conclusion. The present bibliometric analysis shows the research characteristics and trends of FRI from multiple perspectives. The fact that there is an increasing number of studies being published on FRI shows the agreement among scientists and clinicians that standardization with respect to this topic is very important.

1. Introduction

Internal fixation of fractures has revolutionized modern orthopaedic trauma care over the last 50 years. When indicated, internal fixation of fractures can preserve native joints and provide adequate stability to facilitate bone healing without limiting the functional rehabilitation of patients with prolonged immobilization [1]. However, postoperative infections complicate operative fracture management and occur in 1–11% of cases [2–6]. The diagnosis and treatment of postoperative infections are often complex. They require a multidisciplinary approach (i.e., surgeons, infectious disease physicians, and clinical pharmacists), often result in additional surgeries and a long duration of antibiotic therapy [7, 8]. The health care system costs are immense. Trauma patients with a postoperative infection generate inpatient...
costs 6.5-8 times higher than their uninfected counterparts [9]. Despite adequate treatment, clinical and functional outcomes often remain poor, with high dependency rates and an inability to return to work [10].

The terminology surrounding postoperative infections has been historically inconsistent, which has hampered research efforts. Terms such as infection after fracture fixation, surgical site infection, and septic nonunion (or pseudarthrosis) were often used interchangeably but without clear criteria to define the entity [11, 12]. Therefore, in 2017, the term fracture-related infection (FRI) was defined by an international consensus group, including the AO Foundation, Orthopaedic Trauma Association, PRO IMPLANT Foundation, and European Bone and Joint Infection Society [13]. Over the course of the past decades, FRI has increasingly been recognized as a clinical research priority to improve the outcome of this sometimes devastating complication [14–16].

Bibliometrics is a method of statistical analysis used to assess a particular subject’s characteristics and major developmental trends based on published research. Such an analysis has provided useful insight into the global state and trends related to different medical fields [17–21]. Anecdotally, there has been a significant increase in interest in the topic of FRI in recent years through published papers, targeted research grants, and consensus statements. However, till today, bibliometric analysis related to this topic has not been performed. The present study was aimed at describing the overview of clinical studies and trends on FRI between 2000 and 2020.

2. Materials and Methods

2.1. Data Sources and Search Strategy. Bibliometric analysis was performed using the electronic database Web of Science (Science Citation Index Expanded) for articles published between 2000 and 2020. The retrieval strategy used was for the following medical subject headings or keywords: “osteomyelitis,” “septic non-union,” “septic pseudarthrosis,” “septic pseudoarthrosis,” “infected non-union,” “infected pseudarthrosis,” “infected pseudoarthrosis,” “trauma*,” “injurs*,” “fracture*,” “fracture related infection,” “infection

![Figure 1: Flow chart of article selection.](image-url)
after fracture fixation,” “infections after fracture,” “infection after fracture osteosynthesis,” “post-traumatic osteitis,” “post-traumatic osteomyelitis,” “infections associated with fracture-fixation devices,” and “osteomyelitis associated with open fractures.”

2.2. Inclusion and Exclusion Criteria. Inclusion criteria for further analysis were based on the following: (a) article describing a clinical study on FRI in orthopaedics; and (b) review article, meta-analysis, clinical trial, or guideline.

Exclusion criteria were as follows: (a) book chapters, conference proceedings, editorials, errata, or letters; (b) basic science, animal, and cadaveric studies; and (c) nonorthopaedic related fracture or infection, such as of the skull or sternum.

2.3. Data Extraction and Bibliometric Analysis. Data were identified and extracted by three authors individually (CL, AF, NH). All records were exported from the Web of Science database with text and excel document then imported into the software of Bibliometrix (University of Naples Federico II, Italy) and WPS Office (Kingsoft, China) to analyze the result, respectively [22]. Data analysis involves the author, article title, country, journal, h-index, institution, author keywords, language, number of citations, number of publications, and publication year. The impact factor and quartile of the journal were collected from the Journal Citation Reports 2020. The Bibliometrix software was utilized to construct data visualization of international collaborations, top 10 authors’ average output, and trend topics.

3. Results

3.1. Publication Output. A total of 2597 articles met the inclusion criteria using the electronic Web of Science database (Figure 1). The total number of citations related to FRI is 58,690 (51,109 excluding self-citations), with an average citation frequency of 22.6 times per item. Research papers were published in eight languages. More than 94% of articles were written in English (2458), followed by German (91), French (19), Czech (16), Serbian (4), Turkish (4), Spanish (4), and Italian (1).

Figure 2 presents the specific amount of annual publications regarding FRI. Since 2008, the number of articles has exceeded 100 per year. The year 2019 ranked as the most productive year (253), followed by 2017 and 2018 (175 and 171, respectively).

3.2. Country. For the United Kingdom (UK), publications from England, Northern Ireland, Scotland, and Wales were merged [23]. Finally, 89 countries contributed to the FRI publications (Figure 3). Of these, the USA contributed the highest number of articles (814), followed by China (318), the UK (298), and Germany (266; Table 1). The top four countries with the most contribution, each presented more than 10 articles per year between 2016 and 2020 (Figure 4).

Intercountry collaborations were found between 72 countries (Figure 3). The USA had the largest number of collaborations with other countries (46), followed by the UK (35) and France (31; Table 2). The most frequent collaborations were between the USA and Canada (40), followed by the USA and Germany (39), then Switzerland and Germany (32; Table 3).

3.3. Organizations. The top five most productive institutions are listed in Table 4. The most productive organization was the University of California system (48), followed by Harvard University (45) and Vanderbilt University (44). Of the top five most productive organizations, four were based in the USA,
and the remaining was from the University Hospital Leuven, Belgium.

3.4. Authors. A total of 9,842 authors contributed to FRI-related studies. Metsemakers WJ has the highest number of publications with 32 articles, followed by Giannoudis PV (31) and Obremskey WT with 25 publications each (Table 5). Figure 5 demonstrates the average output of the top 10 authors between 2000 and 2020.

3.5. Journals. All included articles were published in 339 different journals. Injury-International Journal of the Care of the Injured had the maximum number of papers (316), followed by the Journal of Orthopaedic Trauma (220) and International Orthopaedics (105; Table 6). The year of the first publication of an FRI study in the respective journal is depicted in Figure 6, with the majority appearing in 2008 and 2019 (24).

Table 1: The top 10 most productive countries in FRI.

| Countries | Records | Total citations | h-index |
|-----------|---------|-----------------|---------|
| USA       | 814     | 25629           | 80      |
| China     | 318     | 4256            | 34      |
| UK        | 298     | 9383            | 49      |
| Germany   | 266     | 6187            | 37      |
| Switzerland | 109   | 3139            | 31      |
| India     | 107     | 1473            | 21      |
| France    | 94      | 2708            | 21      |
| Turkey    | 82      | 1081            | 19      |
| Canada    | 81      | 5055            | 34      |
| Netherlands | 77    | 2854            | 27      |
Data from the 2020 edition of journal citation reports showed 303 journals with an impact factor. The journal with the highest impact factor was The New England Journal of Medicine (74.699), followed by JAMA (Journal of the American Medical) Association (56.272), and Intensive Care Medicine (17.44; Table 7).

![Graph showing annual distribution of FRI research from top 10 countries between 2000 and 2020.](image)

**Figure 4:** The annual distribution of FRI research from top 10 countries between 2000 and 2020.

**Table 2:** Top countries with more than 10 collaborations.

| Ranks | Countries          | Records |
|-------|--------------------|---------|
| 1     | USA                | 46      |
| 2     | United Kingdom     | 35      |
| 3     | France             | 31      |
| 4     | Germany            | 28      |
| 5     | Canada             | 25      |
| 6     | Switzerland        | 23      |
| 7     | Netherlands        | 21      |
| 8     | Australia          | 20      |
| 9     | Belgium            | 20      |
| 10    | Austria            | 18      |
| 11    | South Africa       | 18      |
| 12    | Israel             | 16      |
| 13    | Norway             | 16      |
| 14    | Argentina          | 15      |
| 15    | China              | 15      |
| 16    | Finland            | 15      |
| 17    | Italy              | 14      |
| 18    | Denmark            | 13      |
| 19    | Greece             | 13      |
| 20    | Ireland            | 12      |
| 21    | Japan              | 11      |

**Table 3:** Countries with international collaborations exceeding fifteen.

| From             | To          | Frequency |
|------------------|-------------|-----------|
| USA              | Canada      | 40        |
| USA              | Germany     | 39        |
| Switzerland      | Germany     | 32        |
| USA              | UK          | 30        |
| USA              | Switzerland | 27        |
| Belgium          | Switzerland | 22        |
| USA              | Belgium     | 19        |
| United Kingdom   | Switzerland | 18        |
| USA              | Netherlands | 18        |
| Belgium          | Germany     | 17        |
| UK               | Belgium     | 16        |
| UK               | Germany     | 16        |
All of the top 10 journals with the most number of publications and impact factors were published in English. Journals with more than 10 publications in other languages included Unfallchirurg (German, 40), Revue de Chirurgie Orthopédique et Réparatrice de l’Appareil Moteur (French, 16), and Acta Chirurgiae Orthopaedicae et Traumatologiae Cechoslovaca (Czech, 16).

3.6. Top 100 Most Cited Articles. The number of citations for the top 100 most cited articles was defined according to the number of citations, with citations ranging between 97 and 1004 (Table 8). All included studies were published in 27 different journals, with most publications in the Journal of Orthopaedic Trauma (24), followed by Journal of Bone and Joint Surgery-American Volume (21), and Injury-International Journal of the Care of the Injured (9).

3.7. Trend Topics. Trend topics were identified by author keywords in Bibliometrix. Parameter values were set to a minimum number of keyword occurrences more than 20.
times. The first keywords were presented until 2010, and 36 keywords met the threshold (Figure 7). The top three most frequently used keywords were “infection,” “fracture,” and “complications.” The earliest keywords were “external fixation,” “children,” and “humerus.” The keywords “fracture-related infection,” “diagnosis,” and “risk factor” were the top three latest emerging trend topics of FRI research.

4. Discussion

The current bibliometric study comprised a comprehensive analysis of the scientific output related to FRI, exploring characteristics from publications, languages, countries, institutions, authors, journals, most cited articles, and trend topics. In the current report, we provide scholars with essential references and suggestions for further investigation on FRI.

4.1. Global Publishing Trends. Although some research papers evaluated orthopaedic-related infection using bibliometrics [24, 25], to the best of our knowledge, this is the first article to fully assess clinical research on FRI. Our analysis shows that the number of related publications exhibited a significant increasing trend from 2000 to 2020. Of all languages, English was the main international scholarly language in this field. In addition, 65% of studies in languages other than English was in German. Several bibliometric analyses of medicine-related research also noted that German was the most common second language following English [19, 26].

4.2. Country. Half of the top 10 contributing countries on FRI studies originated from Europe, with the remaining coming from Asia and North America. The UK had the highest number of publications and academic influence in Europe, China in Asia, and the USA in North America. The annual distribution of FRI research from the top 10 countries displayed the USA ranked first in the top 10 largest contribution countries annually between 2000 and 2019.
Interestingly, the UK and Germany persistently remained at around second and third place from 2003 to 2012 (Figure 4). China was ranked second between 2013 and 2019 and first in 2020. This result may suggest a great potential for the development of FRI research in China.

In 72 of 89 countries involved in international collaborations, the USA had the highest number of research collaborations with other countries. Most of the international collaborations were between North America and European countries. A greater international collaboration should be widely established in the future.

4.3. Organizations and Authors. Among the institutions, four of the top five highest contributing countries originated from the USA. The University of California from the USA was the most productive institution globally in clinical studies focusing on FRI. Scholars from Europe and North America demonstrated a dominant position. The publications on the diagnosis and treatment principles of FRI also proved that most members of the FRI consensus group originated from Euro-American countries [27, 28]. In addition, half of the top 10 most productive authors on FRI were involved in the FRI consensus group [13]. Metsemakers WJ, from the University Hospitals Leuven, contributed most to clinical research of FRI. Regarding the top 10 author productions over time, most authors showed increased stability and persistence for a longer duration between 2016 and 2020. The list of top 10 most productive authors in FRI may provide a valuable reference for future scientific conference invitations for FRI experts.

4.4. Journals. Of the top 10 journals with the largest number of papers, Injury-International Journal of the Care of the Injured had the highest number of relevant publications, whereas Journal of Orthopaedic Trauma was the most academic influential journal on FRI. Compared with the bibliometric study, which excludes non-English literature [29, 30], the present bibliometric research also provides more valuable journal information to non-English speaking countries. Hence, scholars will most likely benefit from journal information to further subscribe or track the most relevant journals and also submit clinical research of FRI manuscripts as a reference. Figures on the first publications indicated that an increasing number of journals are interested in FRI research, with the highest values attained in 2008 and 2019.

4.5. Most Cited Documents. The number of citations is a traditional indicator for the assessment of the value of a certain study. Our study displays the top 100 most impactful studies on FRI and provides a resource for clinical scientists. Of all publications, the most cited research paper was published by Govender et al. [31]. The authors found that an implant containing 1.50 mg/mL of recombinant human bone morphogenetic protein-2 in the treatment of open tibial fractures could reduce the incidence of postsurgical infections. The most cited review article was published by Trampuz and Zimmerli [32]. The authors summarized the pathogenesis, classification, diagnosis, and treatment of infections associated with fracture-fixation devices.

4.6. Trend Topics. Trend topics were identified from author keywords. In terms of the surgical site, scholars placed a greater interest in infection after humeral fractures, followed by the location of femur and tibia, with a current focus on ankle fractures [33–39]. Furthermore, research topics and concepts also altered over the course of the years. With the introduction of the FRI consensus group, the term “fracture-related infection” became the standard, with more recent topics primarily focusing on risk factors and diagnostic criteria of FRI [15, 40–43]. Prior to this, researchers focused on the treatment of FRI [44–46], with a focus on debridement, bone transfer, and antibiotic treatment. In addition, with the publication of the consensus definition of FRI, this concept appears to be gradually gaining ground in the scientific literature.

4.7. Limitations. There are several limitations to the present study. First, only a single database was searched, with other databases and sources not included in the bibliometric analysis. Therefore, some potentially valuable information may have been missed [47]. Second, the FRI-related terms of the search strategy were based on the literature and personal

Table 7: Top 10 journals ranked by the impact factor on FRI.

| Source                                                      | Impact factor | Quartile in category | Number of publications | Total citations |
|--------------------------------------------------------------|---------------|----------------------|------------------------|-----------------|
| New England Journal of Medicine                              | 91.245        | Q1                   | 1                      | 104             |
| JAMA (Journal of the American Medical Association)          | 56.272        | Q1                   | 3                      | 90              |
| Intensive Care Medicine                                      | 17.440        | Q1                   | 1                      | 23              |
| British Journal of Sports Medicine                           | 13.800        | Q1                   | 1                      | 8               |
| Bone Research                                                | 13.567        | Q1                   | 2                      | 89              |
| Biomaterials                                                 | 12.479        | Q1                   | 1                      | 260             |
| Age and Ageing                                               | 10.668        | Q1                   | 1                      | 54              |
| Journal of Nuclear Medicine                                  | 10.057        | Q1                   | 1                      | 131             |
| European Journal of Nuclear Medicine and Molecular Imaging   | 9.236         | Q1                   | 6                      | 172             |
| Clinical Infectious Diseases                                 | 9.079         | Q1                   | 6                      | 525             |
| First authors | Article title | Journals | Total citations | Year |
|---------------|---------------|----------|----------------|------|
| Govender, S   | Recombinant human bone morphogenetic protein-2 for treatment of open tibial fractures - a prospective, controlled, randomized study of four hundred and fifty patients | Journal of Bone and Joint Surgery-American Volume | 1004 | 2002 |
| Mckee, MD     | Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures - a multicenter, randomized clinical trial | Journal of Bone and Joint Surgery-American Volume | 517 | 2007 |
| Bhandari, M   | Internal fixation compared with arthroplasty for displaced fractures of the femoral neck - a meta-analysis | Journal of Bone and Joint Surgery-American Volume | 346 | 2003 |
| Gopal, S      | Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia | Bone & Joint Journal | 332 | 2000 |
| Trampuz, A    | Diagnosis and treatment of infections associated with fracture-fixation devices | Injury-International Journal of the Care of the Injured | 291 | 2006 |
| Jamsen, E     | Risk factors for infection after knee arthroplasty a register-based analysis of 43,149 cases | Journal of Bone and Joint Surgery-American Volume | 277 | 2009 |
| Flynn, JM     | Titanium elastic nails for pediatric femur fractures: a multicenter study of early results with analysis of complications | Journal of Pediatric Orthopaedics | 270 | 2001 |
| Widmer, AF    | New developments in diagnosis and treatment of infection in orthopedic implants | Clinical Infectious Diseases | 263 | 2001 |
| Rokkanen, PU  | Bioabsorbable fixation in orthopaedic surgery and traumatology | Biomaterials | 260 | 2000 |
| Castillo, RC  | Impact of smoking on fracture healing and risk of complications in limb-threatening open tibia fractures | Journal of Orthopaedic Trauma | 239 | 2005 |
| SooHoo, NF    | Complication rates following open reduction and internal fixation of ankle fractures | Journal of Bone and Joint Surgery-American Volume | 219 | 2009 |
| Barei, DP     | Complications associated with internal fixation of high-energy bicondylar tibial plateau fractures utilizing a two-incision technique | Journal of Orthopaedic Trauma | 217 | 2004 |
| Fankhauser, F | A new locking plate for unstable fractures of the proximal humerus | Clinical Orthopaedics and Related Research | 212 | 2005 |
| Pape, HC      | Changes in the management of femoral shaft fractures in polytrauma patients: from early total care to damage control orthopedic surgery | Journal of Trauma-Injury, Infection and Critical Care | 210 | 2002 |
| Yazar, S      | One-stage reconstruction of composite bone and soft-tissue defects in traumatic lower extremities | Plastic and Reconstructive Surgery | 205 | 2004 |
| Hak, DJ       | Delayed union and nonunions: epidemiology, clinical issues, and financial aspects | Injury-International Journal of the Care of the Injured | 202 | 2014 |
| Moro, JK      | Arthroplasty with a metal radial head for unreconstructible fractures of the radial head | Journal of Bone and Joint Surgery-American Volume | 201 | 2001 |
| Stannard, JP  | Negative pressure wound therapy after severe open fractures: a prospective randomized study | Journal of Orthopaedic Trauma | 200 | 2009 |
| Sproul, RC    | A systematic review of locking plate fixation of proximal humerus fractures | Injury-International Journal of the Care of the Injured | 197 | 2011 |
| Schmidmaier, G| Prophylaxis and treatment of implant-related infections by antibiotic-coated implants: a review | Injury-International Journal of the Care of the Injured | 194 | 2006 |
| Bhandari, M   | Treatment of open fractures of the shaft of the tibia - a systematic overview and meta-analysis | Bone & Joint Journal | 188 | 2001 |
| O’Neill, KR   | Reduced surgical site infections in patients undergoing posterior spinal stabilization of traumatic injuries using vancomycin powder | Spine Journal | 187 | 2011 |
| Zalavras, CG  | Local antibiotic therapy in the treatment of open fractures and osteomyelitis | Clinical Orthopaedics and Related Research | 186 | 2004 |
| Kregor, PJ    | Treatment of distal femur fractures using the less invasive stabilization system - surgical experience and early clinical results in 103 fractures | Journal of Orthopaedic Trauma | 185 | 2004 |
| Johnson, EN   | Infectious complications of open type III tibial fractures among combat casualties | Clinical Infectious Diseases | 184 | 2007 |
| First authors      | Article title                                                                 | Journals                                           | Total citations | Year  |
|-------------------|-------------------------------------------------------------------------------|---------------------------------------------------|-----------------|-------|
| Robinson, CM      | Adult distal humeral metaphyseal fractures: epidemiology and results of treatment | Journal of Orthopaedic Trauma                       | 177             | 2003  |
| Koval, KJ         | Fractures of the distal part of the radius                                     | Journal of Bone and Joint Surgery-American Volume | 174             | 2008  |
| Yazar, S          | Outcome comparison between free muscle and free fasciocutaneous flaps for reconstruction of distal third and ankle traumatic open tibial fractures | Plastic and Reconstructive Surgery                 | 174             | 2006  |
| Egol, KA          | Staged management of high-energy proximal tibia fractures (OTA types 41) - the results of a prospective, standardized protocol | Journal of Orthopaedic Trauma                       | 173             | 2005  |
| Harris, AM        | Complications following limb-threatening lower extremity trauma                | Journal of Orthopaedic Trauma                       | 169             | 2009  |
| Nowotarski, PJ    | Conversion of external fixation to intramedullary nailing for fractures of the shaft of the femur in multiply injured patients | Journal of Bone and Joint Surgery-American Volume | 169             | 2000  |
| Karger, C         | Treatment of posttraumatic bone defects by the induced membrane technique      | Orthopaedics & Traumatology-Surgery & Research     | 163             | 2012  |
| Chapman, JR       | Randomized prospective study of humeral shaft fracture fixation: intramedullary nails versus plates | Journal of Orthopaedic Trauma                       | 162             | 2000  |
| Arciola, CR       | Etiology of implant orthopedic infections: a survey on 1027 clinical isolates | International Journal of Artificial Organs         | 161             | 2005  |
| Vallier, HA       | Randomized, prospective comparison of plate versus intramedullary nail fixation for distal tibia shaft fractures | Journal of Orthopaedic Trauma                       | 158             | 2011  |
| Im, GI            | Distal metaphyseal fractures of tibia: a prospective randomized trial of closed reduction and intramedullary nail versus open reduction and plate and screws fixation | Journal of Trauma-Injury Infection and Critical Care | 157             | 2005  |
| Swiontkowski, MF  | Recombinant human bone morphogenetic protein-2 in open tibial fractures - a subgroup analysis of data combined from two prospective randomized studies | Journal of Bone and Joint Surgery-American Volume | 156             | 2006  |
| Blauth, M         | Surgical options for the treatment of severe tibial pilon fractures: a study of three techniques | Journal of Orthopaedic Trauma                       | 155             | 2001  |
| Stafford, PR      | Reamer-irrigator-aspirator bone graft and bi Masquelet technique for segmental bone defect nonunions: a review of 25 cases | Injury-International Journal of the Care of the Injured | 154             | 2010  |
| Rechtine, GR      | Postoperative wound infection after instrumentation of thoracic and lumbar fractures | Journal of Orthopaedic Trauma                       | 151             | 2001  |
| Minami, A         | Vascularised fibular grafts - an experience of 102 patients                   | Bone & Joint Journal                               | 150             | 2000  |
| Barei, DP         | Functional outcomes of severe bicondylar plateau fractures treated with dual incisions and medial and lateral plates | Journal of Bone and Joint Surgery-American Volume | 148             | 2006  |
| Prokuskis, I      | Prophylactic antibiotics in orthopaedic surgery                                | Journal of the American Academy of Orthopaedic Surgeons | 146             | 2008  |
| Nork, SE          | Intramedullary nailing of distal metaphyseal tibial fractures                  | Journal of Bone and Joint Surgery-American Volume | 145             | 2005  |
| Skaggs, DL        | Lateral-entry pin fixation in the management of supracondylar fractures in children | Journal of Bone and Joint Surgery-American Volume | 145             | 2004  |
| Pollak, AN        | The relationship between time to surgical debridement and incidence of infection after open high-energy lower extremity trauma | Journal of Bone and Joint Surgery-American Volume | 143             | 2010  |
| Rodriguez-Merchan, EC | Nonunion: general principles and experimental data                          | Clinical Orthopaedics and Related Research          | 142             | 2004  |
| Patzkis, MJ       | Chronic posttraumatic osteomyelitis and infected nonunion of the tibia: current management concepts | Journal of the American Academy of Orthopaedic Surgeons | 141             | 2005  |
| First authors | Article title                                                                 | Journals                                      | Total citations | Year |
|---------------|------------------------------------------------------------------------------|-----------------------------------------------|-----------------|------|
| McKee, MD     | The use of an antibiotic-impregnated, osteoconductive, bioabsorbable bone substitute in the treatment of infected long bone defects: early results of a prospective trial | Journal of Orthopaedic Trauma                  | 141             | 2002 |
| Harley, BJ    | The effect of time to definitive treatment on the rate of nonunion and infection in open fractures | Journal of Orthopaedic Trauma                  | 140             | 2002 |
| Ricci, WM     | Locked plates combined with minimally invasive insertion technique for the treatment of periprosthetic suprachondylar femur fractures above a total knee arthroplasty | Journal of Orthopaedic Trauma                  | 139             | 2006 |
| Naique, SB    | Management of severe open tibial fractures - the need for combined orthopaedic and plastic surgical treatment in specialist centres | Bone & Joint Journal                          | 138             | 2006 |
| Mehlman, CT   | The effect of surgical timing on the perioperative complications of treatment of suprachondylar humeral fractures in children | Journal of Bone and Joint Surgery-American Volume | 138             | 2001 |
| Edwards, C    | Early infection after hip fracture surgery - risk factors, costs and outcome | Bone & Joint Journal                          | 137             | 2008 |
| Knop, C       | Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting | Spine                                         | 137             | 2001 |
| Sebastia-Forcada, E | Reverse shoulder arthroplasty versus hemiarthroplasty for acute proximal humeral fractures. A blinded, randomized, controlled, prospective study | Journal of Shoulder and Elbow Surgery          | 136             | 2014 |
| Benirschke, SK | Wound healing complications in closed and open calcaneal fractures              | Journal of Orthopaedic Trauma                  | 132             | 2004 |
| Filippi, L    | Usefulness of hybrid SPECT/CT in Tc-99 m-HMPAO-labeled leukocyte scintigraphy for bone and joint infections | Journal of Nuclear Medicine                    | 131             | 2006 |
| Anglen, JO    | Comparison of soap and antibiotic solutions for irrigation of lower-limb open fracture wounds - a prospective, randomized study | Journal of Bone and Joint Surgery-American Volume | 131             | 2005 |
| Leung, KS     | Complex tibial fracture outcomes following treatment with low-intensity pulsed ultrasound | Ultrasound in Medicine and Biology             | 131             | 2004 |
| Herrera, DA   | Treatment of acute distal femur fractures above a total knee arthroplasty - systematic review of 415 cases (1981-2006) | Acta Orthopaedica                              | 128             | 2008 |
| Narayanan, UG | Complications of elastic stable intramedullary nail fixation of pediatric femoral fractures, and how to avoid them | Journal of Pediatric Orthopaedics              | 128             | 2004 |
| Harvey, EJ    | Morbidity associated with ORIF of intra-articular calcaneus fractures using a lateral approach | Foot & Ankle International                     | 128             | 2001 |
| Jost, B       | Locking plate fixation of fractures of the proximal humerus: analysis of complications, revision strategies and outcome | Journal of Shoulder and Elbow Surgery          | 127             | 2013 |
| Kettler, M    | Treatment of proximal humeral fractures with the PHILOS angular stable plate. Presentation of 225 cases of dislocated fractures | Unfallchirurg                                  | 127             | 2006 |
| Cassidy, C    | Norian SRS cement compared with conventional fixation in distal radial fractures - a randomized study | Journal of Bone and Joint Surgery-American Volume | 127             | 2003 |
| Sirkin, M     | A staged protocol for soft tissue management in the treatment of complex pilon fractures | Journal of Orthopaedic Trauma                  | 124             | 2004 |
| Metsemakers, WJ | Infection after fracture fixation: current surgical and microbiological concepts | Injury-International Journal of the Care of the Injured | 121             | 2018 |
| Stulik, J     | Minimally-invasive treatment of intra-articular fractures of the calcaneum | Bone & Joint Journal                          | 119             | 2006 |
| Khatod, M     | Outcomes in open tibia fractures: relationship between delay in treatment and infection | Journal of Trauma-Injury Infection and Critical Care | 119             | 2003 |
| Cole, PA      | Treatment of proximal tibia fractures using the less invasive stabilization system - surgical experience and early clinical results in 77 fractures | Journal of Orthopaedic Trauma                  | 117             | 2004 |
| Springer, BD  | Treatment of periprosthetic femoral fractures following total hip arthroplasty with femoral component revision | Journal of Bone and Joint Surgery-American Volume | 117             | 2003 |
| First authors                          | Article title                                                                 | Journals                                                                 | Total citations | Year  |
|---------------------------------------|-------------------------------------------------------------------------------|--------------------------------------------------------------------------|-----------------|-------|
| Metsemakers, WJ                       | Fracture-related infection: a consensus on definition from an international expert group | Injury-International Journal of the Care of the Injured                   | 116             | 2018  |
| Gosling, T                            | Single lateral locked screw plating of bicondylar tibial plateau fractures     | Clinical Orthopaedics and Related Research                               | 116             | 2005  |
| Takeuchi, R                           | Fractures around the lateral cortical hinge after a medial opening-wedge high tibial osteotomy: a new classification of lateral hinge fracture | Arthroscopy-the Journal of Arthroscopic and Related Surgery               | 115             | 2012  |
| Canadian Orthopaedic Trauma Society   | Open reduction and internal fixation compared with circular fixator application for bicondylar tibial plateau fractures - results of a multicenter, prospective, randomized clinical trial | Journal of Bone and Joint Surgery-American Volume                        | 113             | 2006  |
| Yun, HC                               | Osteomyelitis in military personnel wounded in Iraq and Afghanistan           | Journal of Trauma-Injury Infection and Critical Care                     | 111             | 2008  |
| Taeger, G                             | Damage control orthopedics in patients with multiple injuries is effective, time saving, and safe | Journal of Trauma-Injury Infection and Critical Care                     | 111             | 2005  |
| Parsons, B                            | Surgical management of chronic osteomyelitis                                   | American Journal of Surgery                                              | 111             | 2004  |
| Lack, WD                              | Type III open tibia fractures: immediate antibiotic prophylaxis minimizes infection | Journal of Orthopaedic Trauma                                            | 109             | 2015  |
| Borg, T                               | Percutaneous plating of distal tibial fractures preliminary results in 21 patients | Injury-International Journal of the Care of the Injured                  | 108             | 2004  |
| Parameswaran, AD                      | Pin tract infection with contemporary external fixation: how much of a problem? | Journal of Orthopaedic Trauma                                            | 108             | 2003  |
| Suk, SI                               | Anterior-posterior surgery versus posterior closing wedge osteotomy in posttraumatic kyphosis with neurologically compromised osteoporotic fracture | Spine                                                                   | 106             | 2003  |
| Misra, A                              | Complex proximal humeral fractures in adults - a systematic review of management | Injury-International Journal of the Care of the Injured                   | 106             | 2001  |
| Bhandari, M                           | A trial of wound irrigation in the initial management of open fracture wounds | New England Journal of Medicine                                           | 104             | 2015  |
| Aro, HT                               | Recombinant human bone morphogenetic protein-2: a randomized trial in open tibial fractures treated with reamed nail fixation | Journal of Bone and Joint Surgery-American Volume                        | 104             | 2011  |
| Ferran, NA                            | Locked intramedullary fixation vs plating for displaced and shortened mid-shaft clavicle fractures: a randomized clinical trial | Journal of Shoulder and Elbow Surgery                                    | 104             | 2010  |
| Rozbruch, SR                          | Simultaneous treatment of tibial bone and soft-tissue defects with the ilizarov method | Journal of Orthopaedic Trauma                                            | 104             | 2006  |
| Karunakar, MA                         | Body mass index as a predictor of complications after operative treatment of acetabular fractures | Journal of Bone and Joint Surgery-American Volume                        | 104             | 2005  |
| Feldman, DS                           | Correction of tibial malunion and nonunion with six-axis analysis deformity correction using the Taylor spatial frame | Journal of Orthopaedic Trauma                                            | 104             | 2003  |
| Edlund, A                             | Delirium before and after operation for femoral neck fracture                  | Journal of the American Geriatrics Society                               | 104             | 2001  |
| Richards, JE                          | Relationship of hyperglycemia and surgical-site infection in orthopaedic surgery | Journal of Bone and Joint Surgery-American Volume                        | 102             | 2012  |
| Gjertsen, JE                          | More re-operations after uncemented than cemented hemiarthroplasty used in the treatment of displaced fractures of the femoral neck. An observational study of 11 116 hemiarthroplasties from a national register | Bone & Joint Journal                                                   | 101             | 2012  |
| Nasell, H                             | The impact of smoking on complications after operatively treated ankle fractures-a follow-Up study of 906 patients | Journal of Orthopaedic Trauma                                            | 100             | 2011  |
| Lau, TW                               | Wound complication of minimally invasive plate osteosynthesis in distal tibia fractures | International Orthopaedics                                             | 100             | 2008  |
| Fuchs, T                              | The use of gentamicin-coated nails in the tibia: preliminary results of a prospective study | Archives of Orthopaedic and Trauma Surgery                              | 99              | 2011  |
experience; nonetheless, some literature may have been overlooked. Third, conference proceedings were also removed from this bibliometric analysis, due to the potential of being published on two occasions, as a conference abstract and also as a full journal article [48, 49]. Fourth, the number of citations is commonly used to assess the publication quality in bibliometric analysis. To discover high academic impact publications in the clinical research of FRI, we listed the top 100 most cited articles. However, self-citation, publication date, and controversial articles all likely had an impact on the number of citations [21].

5. Conclusions

The number of articles on FRI showed an increasing trend over the last 21 years. English was the primary language used for academic exchange on the topic of FRI, followed by German. In addition, the USA has the most number and impactful publications, as well as international collaborations. China has great development potential in this field. A broader international collaboration on FRI is required in the future. The most relevant and academic influential journals on FRI are the Injury-International Journal of the Care
of the Injured and the Journal of Orthopaedic Trauma, respectively. The definition of FRI will most likely become validated and widely available in clinical practice.

**Abbreviations**

FRI: Fracture-related infection  
USA: United States of America  
UK: United Kingdom.

**Data Availability**

Data is available from the first author upon request.

**Conflicts of Interest**

The authors declare no conflict of interest regarding the publication of this paper.

**Authors’ Contributions**

Cheng Li was responsible for conceptualization, formal analysis, investigation, methodology, writing the original draft, and visualization; Andrew I. Foster and Nicholas Hang Bao Han were responsible for the methodology, investigation, resources, and visualization; Andrej Trampuz and Michael Schuetz edited and reviewed the manuscript. All authors have seen and approved the final version of the paper before submission.

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