Basic Science Research Trends in Orthopedic Surgery: An Analysis of the Top 100 Cited Articles

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Abstract *Background:* Much of current clinical orthopedics traces its origin to basic science investigation of cellular and biochemical pathways, tissue engineering, and biomechanics of bone and joint physiology in animal and cadaveric models. *Questions/Purposes:* We sought to describe research trends in highly cited basic science studies in orthopedics. *Methods:* By searching Web of Science, we identified the 100 most cited basic science orthopedics articles and focused on author position and degree (PhD, MD, or MD/PhD), topic, type of study, country, institution, and citation trends. *Results:* These articles were published from 1970 to 2008 (citation range, 330 to 2111), with the majority from the USA (78). While there was no correlation between years since publication and total citations, more recent articles had higher citation rates. There were 38 unique first authors represented, with Caplan, Harris, Mankin, Noyes, and Warren as primary authors or co-authors of four articles each. Twelve journals published these 100 articles, with the majority in *Journal of Bone and Joint Surgery* (46) and *Clinical Orthopaedics and Related Research* (18). Frequent

topics included biomechanics (31), healing/regeneration (21), and cellular/molecular biology (13). The Hospital for Special Surgery/Cornell University (10) published the most, followed by the Hospital for Joint Diseases/New York University (6), and University of Pittsburgh (6). No difference was observed in total citations and average citation rate by author degree. Eight articles were contributed from privately owned institutions or industry, with the rest from academic hospitals. *Conclusion:* This review may aid those seeking insight into landmark studies and future direction of basic science research in orthopedics.

Keywords basic science · bibliometric analysis · citation analysis · orthopedics

Introduction

Basic science has spurred major advancements in orthopedics that have resulted in significant improvements in clinical practice. Over the past several decades, thousands of influential articles in the field have contributed to clinical advancements and inspired subsequent research. Although it is difficult to measure the impact of research publications, citation analysis is one method that conveys an article's influence in orthopedics [1]. It is believed that the number of times a study has been cited is an indirect marker of its scientific impact, relevance, and exposure. While bibliometric studies have been performed for orthopedics as a whole [4, 6], as well as sports medicine [10], pediatric orthopedics [3, 8], shoulder surgery [9], and arthroscopy [2], no study has focused exclusively on basic science publications. The aim of this study was to identify and describe the 100 most frequently cited basic science publications that may have directly or indirectly contributed to surgical and clinical advancements in orthopedic surgery. We analyzed the authors, academic degrees, journals, institutions and countries of origin, topics, citation trends, and types of

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studies to gain an overview of the most impactful basic science research in orthopedics in the past several decades.

Materials and Methods

Web of Science was used to search all publications from 1900 to 2017 in the field of orthopedics. This database allows the sorting of journal articles by total number of citations. The search included the 25 journals in the field of orthopedics with the highest Eigenfactor scores as rated by the *Journal Citation Reports* database through June 19, 2017 (see Online Resource 1 for a list of journals). The Eigenfactor score, an alternate metric to the more commonly used impact factor, weighs a journal's impact through the number of citations it produces and how likely an average researcher would be to access content from a particular journal, controlling for journal self-citation.

Within these journals, we searched for basic science articles (original and review) that reported on cellular and biochemical pathways, tissue engineering, or biomechanics in animal or cadaveric models. These articles were then further categorized by author position, author degree (MD, PhD, DVM), journal, institution and country of origin, year of publication, topic, type of study, and total number of citations. Significance level was set at a p value of less than 0.05. To avoid repeat citation, these articles are not directly referenced in this study. No funding source played a role in this investigation.

Results

The 100 most frequently cited basic science articles in orthopedics were cited 330 to 2111 times (mean, 521; SD $\pm$ 266) (see Online Resource 2 for the full list of articles). They were published from 1970 to 2008 (mean, 1990; SD $\pm$ 10 years), with articles being in press on average for 27.1 years. Articles were published, in descending order of frequency, in the 1990s (33), the 1980s (32), the 2000s (20), and the 1970s (15). Linear regression analysis showed poor correlation between years since publication and the total number of citations ($R^2 = 0.01$). However, compared with older articles, more recently published work tended to have higher citation rates, calculated by the total number of citations an article received, divided by the number of years published ($R^2 = 0.51$) (Fig. 1).

Online Resource 3 shows how many articles each author contributed to this list by author position and lists the associated topics. Caplan, Harris, Mankin, Noyes, and Warren each contributed four articles in total, with a total of 38 authors listed. Of these 38 authors, the first author held a PhD only (29%), an MD or equivalent only (52%), an MD/PhD (15%), a DVM (2%), or an associate's degree (1%). Among authors with a PhD, MD, or MD/PhD, there was no difference in total citations ($p = 0.46$) or average citation rate ($p = 0.31$) of articles published.

These top 100 basic science articles included publications from 12 journals; contributing a combined 86 articles were *Journal of Bone and Joint Surgery* (46), *Clinical Orthopaedics*

Fig. 1 Citation rate versus publication year. Citation rate is defined by the number of citations an article has received divided by the number of years since publication. An exponential model of regression fits the dataset with an $R^2 = 0.51$.

and Related Research (18), *Journal of Orthopaedic Research* (12), and *American Journal of Sports Medicine* (10) (Fig. 2). The most frequent topics were biomechanics (31), healing and regeneration (21), and cellular and molecular biology (13) (Fig. 3). Biomechanical (cadaveric and animal) research, review articles, and in vivo studies were the most common types (Fig. 4). Most were related to general orthopedics (65), with the others devoted to sports medicine and arthroscopy (15), arthroplasty (11), spine (5), and hand and upper extremity (4).

Most articles were published in the USA (78), followed by Canada (7), Switzerland (4), Sweden (3), UK (3), Russia (2), France (1), Ireland (1), and the Netherlands (1). These publications were submitted from 19 institutions; the Hospital for Special Surgery/Cornell University (10), Hospital

Fig. 2 Journals ranked by number of their articles included in the top 100 most cited basic science orthopedic articles. *JBJS* Journal of Bone and Joint Surgery—American Volume; *CORR* Clinical Orthopaedics and Related Research; *JOR* Journal of Orthopaedic Research; *AJSM* American Journal of Sports Medicine; *O&C* Osteoarthritis and Cartilage; *Injury* Injury—International Journal of the Care of the Injured; *Arthroscopy* Arthroscopy—The Journal of Arthroscopic and Related Surgery; *JOA* Journal of Arthroplasty; *European Spine* European Spine Journal; *JHS* Journal of Hand Surgery—American Volume; *Clin Bio* Clinical Biomechanics.

Fig. 3. Most popular basic science orthopedic topics ranked by number of articles. Parenthesis shows sub-topic.

for Joint Diseases/New York University (6), and University of Pittsburgh (6) contributed the most (Online Resource 4). Eight articles were contributed from a privately owned institution or biotechnology industry and the rest from a university or affiliated hospital.

Discussion

We identified the 100 most frequently cited basic science studies in the field of orthopedics using citation analysis. The majority of articles were published in the 1980s and 1990s, with more recent articles having higher citation rates

despite shorter time in circulation. These articles mostly originated from the USA, with the largest number coming from the Hospital for Special Surgery/Cornell University. Most of these high-impact articles were published in the *Journal of Bone and Joint Surgery*. There was no correlation between number of citations and author degree. The most cited study was a review article, but the majority were original work (74%). Since 2000, there has been a sharp increase in the number of reviews published. There has been a steady but slow increase in the number of in vitro and in vivo studies published since the early 1990s.

As noted by other studies [4, 6], the inherent weaknesses of bibliometric analyses include self-citation (article and

Fig. 4. Types of studies among the top 100 cited basic science studies in orthopedics. Note the sharp increase in the number of reviews published since 2000. While there are few in vivo studies, the number of in vitro studies has increased since the early 1990s. Biomechanical studies, both cadaveric and animal, have been fairly constant.

journal), which is mitigated using Eigenfactor scoring; incomplete references to other sources, such as textbooks or lectures; citation bias, wherein original content is never referenced again; and a snowball effect type of citation, wherein articles are referenced for being previously cited elsewhere. This study is also limited by including only the top 25 journals by Eigenfactor score, which may not necessarily represent most contemporary orthopedic research. For example, in a review discussing current and future direction of basic research in the field [7], 13 of the 27 references were published outside of the 25 journals included in this study. Similarly, in the three most recently published contemporary basic science reviews published in *Journal of Bone and Joint Surgery*, 23% [11], 39% [12], and 36% [13] of the discussed articles were published outside of these 25 journals. These findings suggest that important and potentially groundbreaking studies may come from other fields (e.g., tissue engineering or regeneration, nano-technology, cytokines and growth factors) in journals that are not commonly read by the orthopedic community. Moreover, organizational sponsorship of certain journals may potentially distract readers from quality research published in journals that are less distributed. The most-cited article—authored by Caplan in 1991, titled “Mesenchymal Stem Cells,” and published in *Journal of Orthopaedic Research*—has been cited over 2100 times. The article’s impact is pronounced, in part, because it provides a detailed analysis of the pathway of stem cells from dedifferentiated progenitors to their end products of bone and cartilage. This field has been of widespread interest in recent decades as researchers have delineated the importance of stem cells’ multipotent capacities. The article also explores the clinical relevance of the topic by describing the potential benefit of cell self-repair and of harnessing the progenitor stem cells, which extends into many medical interests related to cell differentiation, bone and cartilage formation, and tissue healing and engineering.

Eight of the top 100 cited papers originated outside of a university setting, three from Cincinnati Sports Medicine and Orthopaedic Center, a private clinic, and five from private companies: Genetics Institute (1) (Cambridge, MA), which was ultimately acquired by Pfizer Inc.; Carbomedics (1) (Austin, TX), still privately held; and Osiris Therapeutics (3) (Columbia, MD), also still privately held. This shows that clinically meaningful translational research can be done in part through private industry and makes a compelling case for continued collaboration between academia and industry.

The uncertain future for funding and the increased complexity of basic science complicate the academic surgeon’s role in translational research. Indeed, the current university-affiliated hospital environment has made it challenging for surgeons to run a productive clinical practice and a basic science laboratory. A recent survey of over 2500 general surgeon-scientists (41% response rate) found three reasons why close to 70% did not believe that surgeons can be successful basic scientists: pressure to be clinically productive, excessive administrative responsibility, and increased desire for work-life balance [5]. The same study also showed a 27% decline in National Institutes of Health (NIH) funding

from surgical departments relative to total NIH funding from 2007 to 2014. However, our study showed no difference in citation rates according to the primary authors’ academic degrees, suggesting that surgeons may still make substantial contributions and remain competitive.

This study identified the most frequently cited basic science articles in the orthopedics literature, which have been cited thousands of times, indicating their scope of influence. This list gives insight into the history of orthopedic surgery, its changes over 40 years, and perhaps where it is headed. This list also identifies institutions that have contributed the most to basic science and journals that have published the most impactful research. The growth in citation rates of more recently published papers is likely secondary to the increased availability of electronic databases. This, in part, may also explain why the number of highly cited reviews is rapidly increasing. As electronic resources become more available, journals are opening doors to wider avenues of publication for authors. This list can serve as an educational tool for trainees and aspiring scientists seeking to build a foundation of orthopedic knowledge by understanding the “landmark” studies in our field.

Compliance with Ethical Standards

Conflict of Interest: Suresh K. Nayar, MD, Eric J. Dein, MD, Johnathan A. Bernard, MD, MPH, Bashir A. Zikria, MD, MSc, and Andrea M. Spiker, MD, declare that they have no conflicts of interest.

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