

Treatment Trends of Adult Brachial Plexus Injury: A Bibliometric Analysis

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Background: Brachial plexus injury is often debilitating because it can severely impair upper extremity function and, thus, quality of life. The surgical treatment of injuries to the brachial plexus is very demanding because it requires a profound understanding of the anatomy and expertise in microsurgery. The aim of this study was to get an overview of the landscape in adult brachial plexus injury surgery, and to understand how this has changed over the years.

Methods: The most frequently cited articles in English relevant to adult brachial plexus injury were identified through the Web of Science online database.

Results: The average number of citations per article was 32.8 (median 24, range 4–158). Authors from 26 countries contributed to our list, and the US was the biggest contributor. Almost half of all nerve transfer cases were described by Asian authors. Amongst nerve transfer, the spinal accessory nerve was the preferred donor overall, except in Asia, where intercostal nerves were preferred. Distal nerve transfers were described more often than plexo-plexal and extra-plexal-to-plexal transfers. The most common grafts were sural nerve grafts and vascularized ulnar nerve grafts, which became popular in the last decade.

Conclusions: Our study sheds light on the regional variations in treatment trends of adult brachial plexus injury, and on the evolution of the field over the last 30 years. The articles included in our analysis are an excellent foundation for those interested in the surgical management of brachial plexus injuries. (*Plast Reconstr Surg Glob Open* 2021;9:e3803; doi: [10.1097/GOX.0000000000003803](https://doi.org/10.1097/GOX.0000000000003803); Published online 15 September 2021.)

INTRODUCTION

Brachial plexus injury occurs in 1% of multi-trauma patients and can be debilitating because it can severely impair upper extremity function and, thus, quality of life.¹ Injuries of the brachial plexus in adults can occur due to trauma (such as road traffic accidents, sports, or gunshot wounds) and due to inflammation or tumors causing traction, stretch, or even avulsion of the plexus.^{2–4}

The treatment of injuries to the brachial plexus is very demanding because it requires a profound knowledge of anatomy and expertise in peripheral nerve surgery and microsurgery.⁵ Attempts at surgical repairing of the brachial plexus have been reported for centuries,

and the successful repair of the brachial plexus was first reported in 1896.⁶

However, quite some time passed until surgery of the brachial plexus was pursued again. In the 1970s, the first fascicular nerve grafting techniques were described by Millesi² and Narakas⁷; in the 80s, the first nerve allotransplantation was described by Mackinnon⁸; in the 90s, reconstructions using extra-plexal sources for reinnervation of vascularized muscle transfers were reported; and over the last two decades, nerve transfers have become increasingly popular as part of the reconstructive strategy.²

Citation analysis can be helpful in identifying the most cited and impactful articles for a given topic. Numerous citation analysis studies have been performed in diverse medical fields and surgical subspecialties such as plastic surgery,⁹ global surgery,¹⁰ burns,¹¹ craniofacial surgery,¹² microsurgery,¹³ and hand surgery.¹⁴ These studies are concise and valuable reference tools that enable readers to understand the characteristics of the most cited articles,

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hence providing a succinct overview of a field for those interested to learn more about it.

AIM

The aim of our study was to provide a general overview of the landscape in adult brachial plexus injury surgery, and to understand how this has changed over the years.

METHODS

The most frequently cited articles in English relevant to adult brachial plexus injury (ABPI) were identified through an online database [Web of Science, version 5.16.1, Thomson Reuters (London, UK)] of the Science Citation Index of the Institute for Scientific Information in October 2019. The terms “traumatic brachial plexus injury” and “adult brachial plexus injury” were used to search by topic. No limitation was applied to the search in subject category, journal, or publication year.

A total of 1017 articles were found in the initial search. These articles were ordered in descending order of “times cited.” The title and abstract of each citation were reviewed, and those that were not directly related to the repair of adult brachial plexus injury were removed. Epidemiological and basic science articles; radiological, anatomical, and diagnostic studies; case reports; and articles about pediatric or neonatal-obstetric brachial plexus injury were also excluded.

The following data were extracted from each included article: title, source journal, publication year, total citations, average citations per year, authors, topics, subspecialty, country of origin, and institution of origin. The country and institution of origin were determined by the address listed for the first author, while the subspecialty was determined in two ways: firstly, the subspecialty of each article was determined by the main subspecialty of the journal in which an article was published—for example, articles published in *Neurosurgery* fell under neurosurgery. Secondly, the subspecialty was determined based on the department of the first author of each article—for example, if the first author belonged to an orthopedic surgery department, orthopedics was also the subspecialty of that article.

The variables for each article were recorded into a computerized spreadsheet (Microsoft Excel 2013; Microsoft Corporation, Redmond, Wash.). Because this citation analysis was performed using published data, no institutional review board approval was required.

RESULTS

The 100 most cited articles on the treatment of brachial plexus injury in adults had a combined 3276 citations from 1991 to 2017. The number of citations per article ranged from 158 for the top article to four for the 100th article, with a mean of 32.8 citations per article and a median of 24. The citation index was created to represent the number of annual citations since the publication of each article. This ranged from 0.71 to 9.56 citations per

year, with a mean of 2.75 citations per year. The number of articles published on the topic of ABPI has increased over the years, with the topic appearing to be most popular between 2010 and 2015.

Table 1 represents the basic information of the top 10 articles included in our analysis, while the basic information on all articles can be found in SDC 1. (See table, Supplemental Digital Content 1, which displays the basic information of the 100 articles included in our analysis, in descending order of citations received. <http://links.lww.com/PRSGO/B774>.)

Authors from 26 countries contributed to our list; Americans were the biggest contributors with 26 publications, followed by Chinese (11), British (nine), Brazilian (eight), and Taiwanese (seven) authors (Fig. 1). Overall, Asians authored most of the articles (34).

The Mayo Clinic was the institution with most first authors on our list (USA, nine), followed by Chang Gung Memorial Hospital (Taiwan, five), Mahidol University (Thailand, five), and the University of the South of Santa Catarina (Brazil, four).

ARTICLES BY SUBSPECIALTY

All of the articles included in our list were published in 35 journals, with the *Journal of Neurosurgery* being the most popular journal, featuring 12 articles, followed by the *Journal of Hand Surgery – American Volume* and *Plastic and Reconstructive Surgery*, which published 11 articles each. When assessing the subspecialty of each article based on the journal in which it was published, neurosurgery was the most prominent subspecialty, followed by plastic surgery and hand surgery. In Europe and South America, most articles were published in neurosurgery journals while in North America most were published in plastic surgery journals, and lastly in Asia the majority of research was featured in hand surgery journals.

On the other hand, when assessing the subspecialty of each article based on the first author’s department, most articles were authored by orthopedic surgeons followed by plastic and neurosurgeons. The research output of orthopedic surgeons also increased the most over time. The regional distribution of subspecialties of the authors was similar to that of the subspecialties based on journals, except for orthopedics, where most articles originated from Asia (Fig. 2).

ARTICLE TYPES

Eight of the included publications were systematic literature reviews, 24 were expert reviews of various treatment options, two were experimental clinical trials, one was a pilot study, seven were prospective studies and seven were case series, 51 were retrospective studies, and of those, four were comparative.

SYSTEMATIC LITERATURE REVIEWS

Of the eight systematic literature reviews included in our list, the objective of four was to study the overall

Table 1. Basic Information of the Top 10 Articles Included in Our List of 100 Articles, in Descending Order of Citations Received

	Title	Authors	Source Title	Institution	Country	Total Citations	Citation Index
1	Outcomes of brachial plexus reconstruction in 204 patients with devastating paralysis	Terzis JK, Vekris MD, Soucacos PN	<i>Plastic and Reconstructive Surgery</i>	Microsurgical Research Center	USA	158	7.52
2	Spinal nerve root repair and reimplantation of avulsed ventral roots into the spinal cord after brachial plexus injury	Carlstedt T, Anand P, Hallin R, Misra PV, Noren G, Seferlis T	<i>Journal of Neurosurgery</i>	Karolinska Hospital	Sweden	121	6.05
3	Adult traumatic brachial plexus injuries	Shin AY, Spinner RJ, Steinmann SP, Bishop AT	<i>Journal of the American Academy of Orthopaedic Surgeons</i>	Mayo Clinic MN	UK	110	7.33
4	The surgical treatment of brachial plexus injuries in adults	Terzis JK, Papakonstantinou KC	<i>Plastic and Reconstructive Surgery</i>	Eastern Virginia Medical School	USA	110	5.5
5	Complete traumatic brachial plexus palsy – Treatment and outcome after repair	Bentolila V, Nizard R, Bizot P, Sedel L	<i>Journal of Bone and Joint Surgery – American Volume</i>	Hôpital Lariboisière	France	96	4.57
6	Spinal accessory neurotization for restoration of elbow flexion in avulsion injuries of the brachial plexus	Songcharoen P, Mahaisavariya B, Chotigavanich C	<i>Journal of Hand Surgery – American Volume</i>	Mahidol University	Thailand	95	3.96
7	Brachial plexus injury: A survey of 100 consecutive cases from a single service	Dubuisson, AS, Kline, DG	<i>Neurosurgery</i>	Domaine Universitaire du Sart Tilman	Belgium	90	5
8	Comparison of nerve transfers and nerve grafting for traumatic upper plexus palsy: A systematic review and analysis	Garg, Rohit, Merrell, Gregory A, Hillstrom, Howard J, Wolfe, Scott W	<i>Journal of Bone and Joint Surgery – American Volume</i>	Hospital for Special Surgery	USA	86	9.56
9	Current concepts of the treatment of adult brachial plexus injuries	Giuffre JL, Kakar S, Bishop AT, Spinner, RJ, Shin AY	<i>Journal of Hand Surgery – American Volume</i>	Mayo Clinic MN	USA	82	8.2
10	Surgical reconstruction of the musculocutaneous nerve in traumatic brachial plexus injuries	Samii M, Carvalho GA, Nikkhah G, Penkert G	<i>Journal of Neurosurgery</i>	Nordstadt Hospital and Medical School	Germany	78	3.39

outcomes of specific procedures: three of them dealt with contralateral C7 nerve transfers and one of them was on the use of the phrenic nerve transfer to the musculocutaneous nerve. All three studies evaluating the use of the contralateral C7 as a donor nerve found that there was no clear benefit in using contralateral C7 over other nerves,^{1,15,16} and one of the studies found that when using the contralateral C7 nerves, the donor site morbidity is high.¹⁶

De Mendonca Cardoso et al found that phrenic nerve transfer to the musculocutaneous nerve are successful in recovering bicep strength of M3 or greater (British Medical Research Council) in most patients with traumatic brachial plexus injury. Furthermore, they found that the development of pulmonary symptoms is rare.¹⁷

The other four systematic literature reviews aimed to compare treatment options: two compared nerve transfers to nerve grafts and one compared nerve transfers to nerve repair. All three studies found that nerve transfers to be superior to nerve reconstruction in the restoration of elbow flexion,^{1,18,19} and two of them also found nerve transfers to be superior in the restoration of shoulder abduction.^{18,19} Finally, Hoang et al compared nerve reconstruction to free muscle transfer for the recovery of elbow flexion and found that in late presentation of traumatic brachial plexus injuries, donor nerves should be reserved for free functional muscle transfers to restore elbow flexion instead of being used for reconstruction.²⁰

EXPERIMENTAL STUDIES

The aim of both experimental studies was to use nerve allografts in the clinical scenario, and both studies showed that nerve allograft transplantation may be performed safely when the patients are carefully selected and screened.^{21,22}

EXPERT REVIEW ARTICLES

From the expert review articles, 14 broadly reviewed all available options for the surgical reconstruction of the adult brachial plexus,^{5,23–35} while the remaining 10 focused on a specific topic: four focused on nerve transfers,^{36–39} one of which also focused on free muscle transfers³⁹; one article was about tendon transfers,⁴⁰ another article was specifically about the management of root avulsions⁴¹; two focused on the timing of the reconstructions^{42,43}; one dealt with late reconstruction,⁴⁴ and lastly, one article focused on outcome measures.⁴⁵ Two authors wrote more than one of the expert opinion reviews: Julia K. Terzis and David C.C. Chuang authored three articles each.

Julia K. Terzis was also the author of the most cited article, titled “Outcomes of brachial plexus reconstruction in 204 patients with devastating paralysis.”⁴⁶ (Table 1). This is a retrospective study, which reviewed the outcomes of the surgical reconstruction of the brachial plexus in a cohort of 204 patients. The authors used several reconstructive techniques: nerve reconstruction included 577 nerve repairs; microneurolysis was performed in 89 cases.



Fig. 1. Map showcasing the countries of origin of the first authors of the articles included in this study.

Vascularized nerve grafts were used in 120 repairs. Muscle transfers were also used. The authors found that postganglionic lesions had a significantly better outcome than avulsion injuries. They also concluded that denervation time played a significant role in outcomes, especially in shoulder reconstructions.

RETROSPECTIVE AND PROSPECTIVE STUDIES

When analyzing the retrospective and prospective studies, as well as case series, we found that the authors of 54 of these studies used nerve transfers, while nerve grafts were used in 42 of these articles. Almost half of all nerve

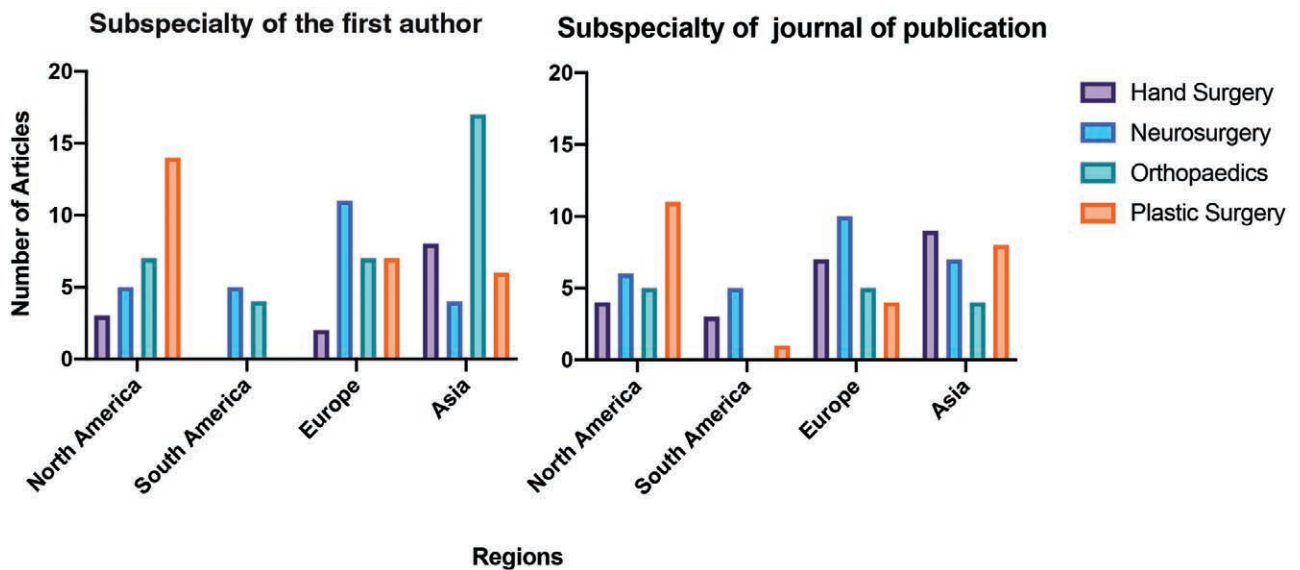


Fig. 2. The subspecialty of the journals of publication vs that of the first authors, by region.

transfers cases were described by Asian authors (23); on the other hand, nerve grafts were used in all regions evenly. The use of nerve transfers and grafts appears to have risen in popularity in all continents except for Europe, where it has remained stable.

NERVE TRANSFERS

Amongst nerve transfer, the spinal accessory nerve was the preferred donor overall (36). Other popular donor nerves were the intercostal nerves (27), phrenic nerves (20), plexo-plexal transfers (18), contralateral C7 transfers (13), and Oberlin (ulnar) transfers (10) (Fig. 3). North American articles had the most variability in the choice of donor nerves, describing 15 different options. Asia had 13, Europe, 11, and South America, 10. All types of donor nerves have become more popular over the years, with the exception of plexo-plexal transfers. Oberlin transfers only appeared amongst our articles in the early 2000s, despite the original article describing the technique being published in 1994.⁴⁷ This article was not included in our study because it consisted of an anatomical study with four case reports.

There were some inter-regional differences: in Asia, the intercostal nerves were preferred over the spinal accessory nerves, while in Europe plexo-plexal transfers were almost as popular as spinal accessory nerve transfers and more popular than intercostal nerve transfers. In South America, spinal accessory nerve transfers were the most frequent, followed by Oberlin transfers, while in North America, spinal accessory, intercostal, and plexo-plexal transfers were used with almost the same frequency.

When dividing the transfers mentioned in the articles into distal transfers, plexo-plexal and extra-plexal to plexal transfers, 47% of them were distal, 35% extra-plexal to plexal, and the remaining 23% were plexo-plexal. Both extra-plexal to plexal and plexo-plexal transfers first appeared amongst our articles in 1995. The number of distal and extra-plexal to plexal transfers has increased over the years, while that of plexo-plexal ones has decreased with time (Fig. 5). The majority of Asian authors described distal repairs, while North American authors described extra-plexal to plexal repairs more frequently.

NERVE GRAFTS

Sural nerves were by far the most common nerves to be harvested for a graft, appearing in 23 of the articles that described nerve grafting. This was followed by vascularized ulnar nerve grafts, which became frequently described by Asian and North American authors over the last 10 years (Fig. 4).

FREE MUSCLE TRANSFERS

Fifteen articles described the use of free muscle transfers, and the gracilis was by far the most commonly used muscle. The popularity of free muscle transfers also increased in recent years: 15 articles, and four of those were published in the last 5 years (Fig. 8). Furthermore, free muscle transfers first appeared amongst the articles on our list in 1996, and then were not mentioned in any of the articles published between 2000 and 2008.

TENDON TRANSFERS

Seven articles described the use of tendon transfers. In each, the authors used different techniques, with no apparent favored method for the restoration of shoulder abduction and elbow flexion, respectively.

DISCUSSION

The 100 publications included in this review provide a broad overview on the treatment trends for ABPI. Our analysis highlights that in general, the research on ABPI has increased in popularity over the last 30 years.

This raise in popularity appears to be similar across all regions except for Europe, where the research output has remained relatively stable. There could be a multitude of explanations for this: for example, in some countries, such as the Philippines and Thailand, research might not have been as prominent in the last century due to low resources or funding allocations. Perhaps this has changed over the last couple of decades, driving a shift toward research culture amongst surgeons, while, in contrast, in countries such as the United States, research has been a staple of a surgeon's career for a long time as well as being heavily funded.⁷

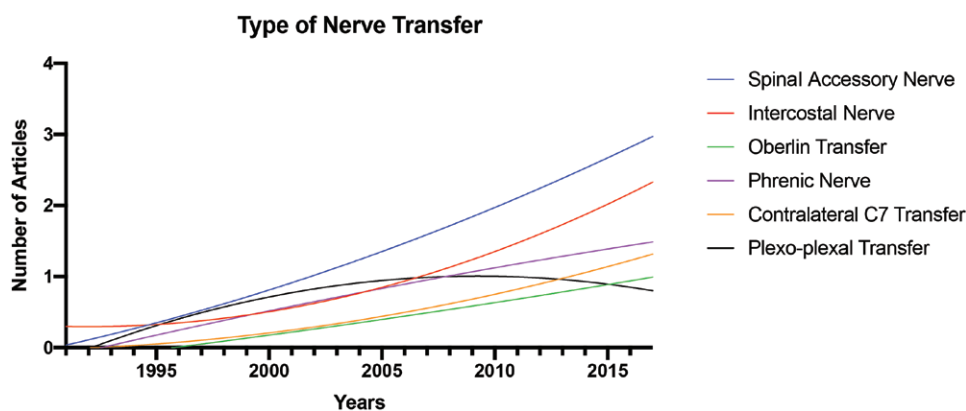


Fig. 3. Graph showing the trends of the use of specific nerve transfer types—this was derived from the number of case series, retrospective and prospective studies that describe a specific type of nerve transfer each year.

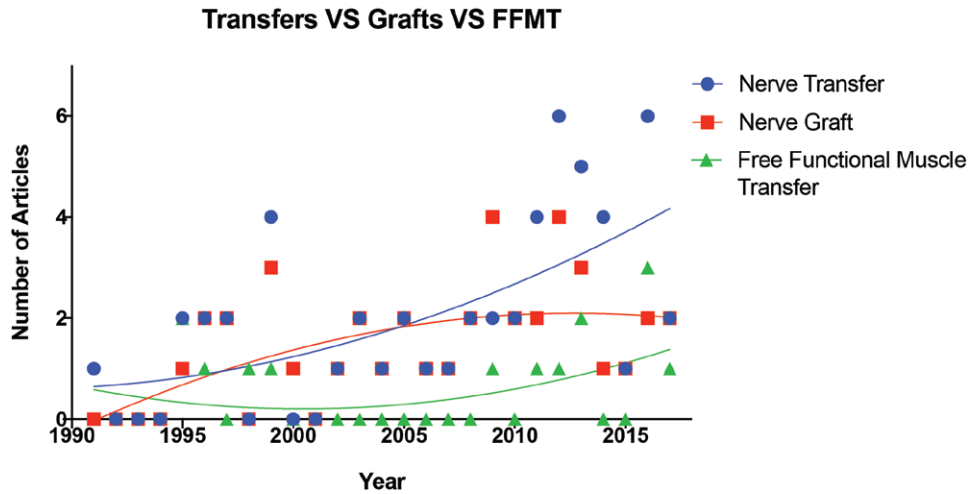


Fig. 4. Number of case series, and retrospective and prospective studies describing nerve transfers, nerve grafts, and free functional muscle transfers each year.

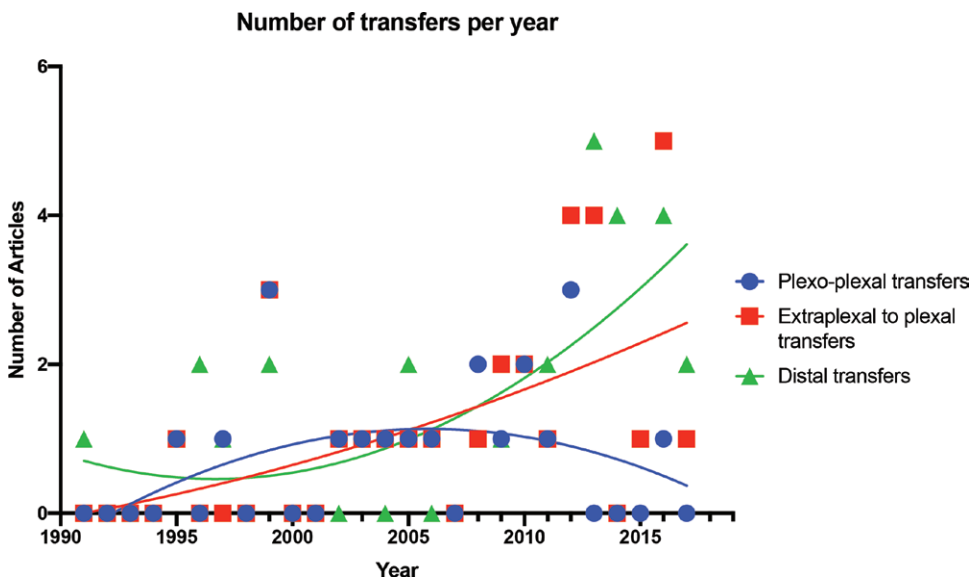


Fig. 5. Number of case series, and retrospective and prospective studies describing plexo-plexal, extraplexal to plexal, and distal nerve transfers each year.

An interesting finding was the discrepancy between the distribution of surgical subspecialties of the journals in which the articles were published versus the first author’s department. Although 34% of authors belonged to orthopedic surgery departments, only 14% of the articles were published in orthopedic surgery journals. Furthermore, contributions from orthopedic surgeons have increased over the years, with over half of their articles being published in the last decade. Meanwhile, the number of authors and publications in plastic surgery and neurosurgery was proportional, and their contribution remained relatively constant over the years. One possible explanation could be that while microsurgery has been a staple technique for both plastic and neurosurgeons,⁴⁸⁻⁵⁰ it has only recently become part of an orthopedic surgeon’s curriculum.^{51,52} Although orthopedics has always played a big role in the treatment of ABPI with tendon

transfers, arthrodesis etc, microsurgery is crucial for the nerve reconstructions of brachial plexus injuries. Thus, it is likely that with the acquisition of microsurgery skills, orthopedic surgeons have become more involved in the overall treatment and research on ABPIs, and perhaps when choosing the right journal for the publication of their articles, plastic, hand and neurosurgery journals might have had a better historical record of publishing articles on ABPI, thus appearing to be a more appropriate choice compared with orthopedic journals.

Another discrepancy was found between the number of publications in hand surgery and the number of articles contributed by hand surgeons: 23% of the articles were published in hand surgery journals, whereas only 13% of the surgeons belonged to hand surgery departments. The explanation for this finding may be simpler: in many countries, hand surgery does not exist as a stand-alone

specialty; rather it is part of the plastic or orthopedic surgery departments. Meanwhile, there are several journals dedicated exclusively to hand surgery.

Our study included more articles describing distal repairs than those describing proximal repairs, with this difference becoming more marked over time. The cause for this shift is most likely multi-factorial: the last two decades have seen the introduction of many new techniques for the improvement of function following ABPI: from Oberlin transfers to free muscle transfers to vascularized nerve grafts, surgeons might prefer these approaches to proximal repairs, where the options for repair remain more limited. The systematic literature reviews included in our study show that nerve transfers had better outcomes than nerve repairs,^{1,18,19} and that free muscle transfers were superior to nerve repairs in late presentations,²⁰ while the most cited article noted that outcomes were better when the distal coaptation of nerve grafts was closer to the muscle target.⁴⁶ This difference in outcomes might also be pertinent to our findings. Finally, proximal repairs might be technically more challenging due to the complex anatomy of the brachial plexus.

LIMITATIONS

There are several potential limitations arising from the bibliometric analysis study design. Citation analysis itself is not a flawless indicator of true scholarly impact and there is a risk of bias; self-citing bias, for example, can happen due to national citing, which when local articles are preferentially cited and selected when submitted to journals⁵³; omission bias happens when authors deliberately omit referencing another article as both articles have conflicting findings.⁵⁴ Only publications in English were included, which might lead to language bias—that is, citing only articles published in a specific language (usually English), although similar articles in other languages might also be available. The authors of this study opted to use the Web of Science database based on the precedence of previously published bibliometric analyses, but different databases might have resulted in a different set of publications. Finally, the amount of citation does not necessarily reflect the true popularity of a certain procedure, but rather the recognition within the scientific community.

The analysis of the prospective and retrospective studies in our list focused on the different surgical techniques available to treat ABPI; however, due to paucity of information, we were not able to divide the articles by type of ABPIs (acute versus longstanding injury, level of injury etc), which all have respective treatment indications. This would have certainly shown interesting results, and could have helped explain some of the treatment preference trends observed in our analysis.

CONCLUSIONS

Our study sheds light on the regional variations in treatment trends of ABPI as well as on the evolution of the field over the last 30 years. Asians authored the most articles. This study highlights a discrepancy between the distribution of

articles by surgical subspecialty when based on the journal of publication versus the first author's department, as well as that the authors of the articles included in this analysis preferred distal transfers over proximal ones. Finally, the articles included in our analysis are an excellent foundation for those interested in the surgical management of brachial plexus injuries and its development over time.

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