The Canadian Chiropractic Research Enterprise 2012-2017

Brian S. Budgell, DC, PhD
Nora Bakaa, BSc, DC
Kyle Stunden, BSc, DC

Authors

Brian S. Budgell, DC, PhD
Director of Life Sciences Laboratories
Canadian Memorial Chiropractic College
6100 Leslie St.
Toronto, Ontario
Canada M2H 3J1
bbudgell@cmcc.ca
ORCID iD: 0000-0001-6095-0794

Nora Bakaa, BSc, DC
Graduate Student, Faculty of Health Sciences
School of Rehabilitation Sciences
McMaster University
norabakaa@gmail.com
ORCID iD: 0000-0002-4560-5877

Kyle Stunden, BSc, DC
Walnut Grove Chiropractic & Massage Therapy
110-8814 216 Street
Langley, B.C.
kyle.stunden@hotmail.ca
ORCID iD: 0000-0002-5017-3212

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Forward

Research is defined by Webster's dictionary as: "investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws". Thus, any profession involved in the pursuit of scientific knowledge, particularly in the healing arts, owes a debt to society (and to itself) to pursue robust, unbiased (as far as possible), high quality research. Such an enterprise strives to provide novel therapeutics, evaluate contemporary therapies (efficacy over time, cost-effectiveness) and/or to propose new directions of inquiry or practice.

The Chiropractic profession has historically faced challenges due (amongst other aspects) to its relative isolation from 'main-stream' healthcare organizations/institutions, limited access to a collaborative community, and lack of graduate training, infrastructure and organization. To better understand how (or if) chiropractic interventions are helpful to patients, significant effort has been dedicated to scientific research under this broad area of inquiry. These efforts within the profession have earned the colloquial moniker 'chiropractic research', likely as a contrast to 'medical research', perhaps to demonstrate a sense of independence. However, the pursuit of science should not depend upon an ideology (that is the realm of politics); rather, science should stand on its own. The term 'medical research' has historical roots that date back to the first ever experiment resembling a clinical trial as recounted in the "Book of Daniel" in The Bible. In this account, King Nebuchadnezzar ordered his subjects to eat meat and drink wine, but some of his subjects objected and stuck to an herbivorous diet. Their respective health was assessed later and the herbivore sorts appeared better nourished, thus completing the first 'clinical trial'.1 Thus, no particular profession can rightly 'own' research, however chiropractic is a young healing art and, in an effort to differentiate itself and establish a measure of independence, the term 'chiropractic research' has emerged. Those within the profession likely understand the nuances of the term, however to others it may appear self-serving since such research covers the gamut from basic science to clinical trials, just as is the case with the more classically understood "medical research".

No doubt, as presented in the following work, there have been attempts to make fundamental changes in this regard with respect to funding, training investigators and the publication of peer-reviewed research. The question remains as to how the time, effort and investment involved results in a quantifiable impact upon matters important to the profession on the one hand, but to society on the other - and can both objectives be concurrently satisfied? Important questions addressed within the following manuscript concern: In what scientific publications does chiropractic-related science appear? Do these papers create meaningful impact? Do the relevant investigators create and/or work collaboratively? If so, with whom and has this work led to desired outcomes? From the data presented in the following manuscript, what lessons have been learned that may inform future decision making? Should the term 'chiropractic research' be abandoned?

The following manuscript attempts to create what is likely the first quantitative study examining the scientific basis of chiropractic-related investigation and the impact of the investigations performed by chiropractors (clinicians, scientists, clinician/scientists). This is the first of such attempts to apply innovative social network metrics to an elusive topic and may offer necessary insight into what has been accomplished to date and, perhaps more importantly, what should come next?

References

1. Collier Roger. Legumes, lemons and streptomycin: A short history of the clinical trial. Canadian Medical Association Journal Jan 6; 180, 23-24, doi:10.1503/cmaj.081879 (2009).

W. Mark Erwin DC, PhD
Assistant Professor,
Divisions of Neurological and Orthopaedic Surgery,
The Spine Programme,
University of Toronto,

Associate Professor, Research, CMCC

Introduction

Chiropractic care is now a fixture in the Canadian health care landscape, and yet acceptance by other health care professions is constrained. While there is evidence of acclimation by medical practitioners toward the use of chiropractic care for a circumscribed set of musculoskeletal disorders [1], there is also considerable concern about the broader scope application of chiropractic care, particularly in children [2, 3], and hesitancy toward even the most tangential association between Canadian medicine and chiropractic [4]. Criticisms of contemporary chiropractic in Canada appear to focus on deficiencies in the scientific basis of the discipline, especially the lack of evidence of clinical efficacy for particular applications, and the lack of understanding of the target of spinal manipulation, when that target is referred to as 'subluxation.' Concerns expressed by medical authors or in medical publications are often mirrored in the chiropractic literature (for example, see [5, 6]).

In reality, it seems that the Canadian chiropractic profession is generally supportive of the concept of evidence based care [7]. Nonetheless, one may fairly ask whether the profession is pulling its weight in terms of generating a robust scientific basis for its clinical practices. In this regard, a number of initiatives have attempted to define a research agenda for the profession, often with an emphasis on clinical questions [8, 9]. However, to date there has been no quantitative assessment of the allocation of resources and the research output attributable to the profession. Furthermore, little attention has been paid to how researchers interact with each other and society. Hence, the purpose of this study was to quantify and characterize the research output attributable to the Canadian chiropractic profession for the years 2012 to 2017, inclusive, and to examine interactions between researchers, funders and publishers using social network analysis.

Methods

A directory of Canadian chiropractor-researchers was developed by downloading the list of funded researchers from the Canadian Chiropractic Research Foundation (CCRF) website (https://canadianchiropracticresearchfoundation.ca) and obtaining the list of faculty researchers from Canadian Memorial Chiropractic College's (CMCC) Office of Research Administration. Peer-reviewed research publications were identified by searching PubMed for original research articles authored by the 50 CCRF-funded researchers and published between January 1, 2012 and December 31, 2017. The original searches were conducted in August and September 2017, and updated on February 15 2018. CMCC-affiliated authors were contacted directly and asked to submit their own lists of peer-reviewed publications. Additionally, the college's Office of Research Administration provided its comprehensive list of research articles attributed to CMCC in the years 2012 to 2017. Furthermore, on March 14, 2018, PubMed was searched for all articles published between Jan 1, 2012 and Dec 31, 2017 with the affiliation 'Canadian Memorial Chiropractic College.'

Finally, on January 24, 2018, a search was made of the Index to Chiropractic Literature (https://www.chiroindex.org) with publication dates of 2012 to 2017. The records were downloaded as a text file, transferred to Microsoft Word to delete numbering, and then pasted into a Microsoft Excel worksheet. The list was ordered alphabetically by author and then papers with no Canadian authors were deleted.

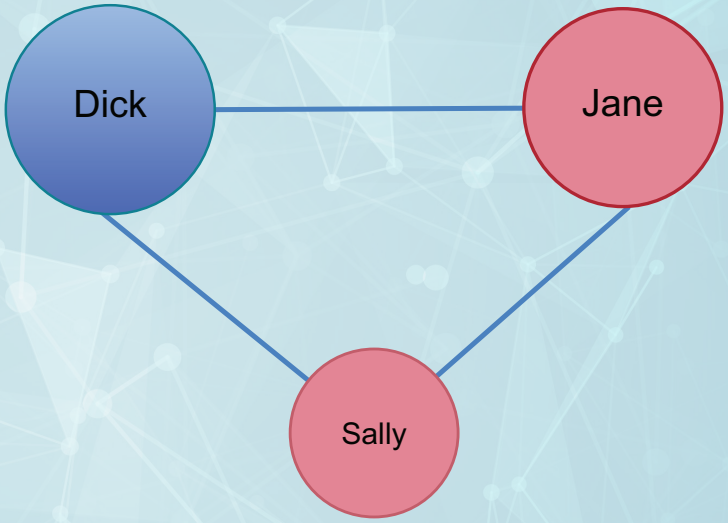
Two researchers reviewed all retrieved articles to eliminate those which did not contain original data. From the corpus of research articles, the following data types were extracted: title and abstract, corresponding author, co-authors, funding sources, author affiliations, journal name, and journal impact factor. For papers with more than 20 coauthors, only the first 20 coauthors were recorded. Papers were parsed into a taxonomy consisting of i) reviews, meta-analyses and clinical guidelines, ii) prospective clinical studies, iii) retrospective cohort studies, iv) case studies and case series, v) surveys and epidemiological studies, vi) diagnostic and prognostic studies, vii) studies of design, including pilot studies and protocols, viii) basic scientific studies and ix) studies within the domains of the social sciences and humanities, including education. From the list of authors, we calculated an author statistic which we called attributable authorship, which refers to the total number of papers an author is listed on divided by the total number of authors on all of those papers. This statistic provides one additional measure of an author's productivity and is useful in mapping output since the 'space' occupied by a paper on a network map is not magnified by the number of authors. Data were entered into an Excel workbook and tables of corresponding types of data were constructed manually to test for associations. While a number of software packages are available to perform these functions automatically, they tend to be challenged when it comes to disambiguation of authors' names (and to a lesser degree, journal and funder names). In this regard, disambiguation of authors' names obtained from searches of the electronic data bases was greatly aided by access to publication lists solicited directly from authors and CMCC's office of research administration.
Associations between data types were plotted in Gephi 0.9.2 (https://gephi.org), an open-access social network mapping application, to construct various network maps. Networks were mapped using the ForceAtlas 2 algorithm. This algorithm treats all 'nodes' as if they are mutually repellent, but all connections as if they are weighted attractions. Hence, the nodes self-distribute in the virtual space created by the program such that connected nodes aggregate and un-related nodes disperse. Social network analysis (SNA) has been used by a number of meta-researchers to characterize research networks; particularly to identify key researchers, collaborations and drivers of research [10-12].

The statistical package within Gephi was used to calculate various measures of centrality, which in broad terms refers to the importance or influence of a member within a network. In particular, betweeness centrality was used to identify nodes or members (authors, journals, funders) which might be thought of as conduits of knowledge or power within their networks. Eigenvector centrality was also used to identify what might be thought of as significant communities or cliques among authors. This latter analysis was supplemented by using the modularity function within Gephi to identify communities.

Social Network Analysis

Social network analysis is a set of methods for studying the interactions of members of a community. These days, and especially with the explosion of social media, the members are often real people who genuinely interact, at least to some degree, within a defined social network, such as Facebook or Twitter. However, the same methods can be applied to more abstract 'members' such as organizations and ideas, and, in fact, the core methods of analysis were around long before electronic social networks arose.

What is new is the fairly widespread availability of computer programs which make social network analysis accessible to non-experts. In this study, we made use of the open-source program Gephi *(https://gephi.org/)*, which is now about a decade old and so has a variety of tried and true add-ons, and provides versatile, attractive visualizations of networks generated from user-input data. The data consist of members, often referred to as *'nodes'* and the connections between those members, referred to as *'edges.'* Hence, the visual output consists of a graph which is essentially a map showing *nodes,* perhaps as circles, connected by *edges,* perhaps straight or curved lines. The sizes of nodes on the map can be scaled to any property the user inputs. In some instances in this study, we scaled the sizes of *nodes* representing authors to the number of publications that each author appeared on. *Node* colours can also be associated with some property such as affiliation, geographical location and so forth. By way of example, three storybook siblings are represented below, with *node* sizes scaled to their ages and *node* colour, with apologies for the cliché, parsed according to gender.



Various algorithms can be used to generate metrics of the network as a whole, and its individual members. Among these metrics are various measures of connectedness, commonly referred to as *centrality*. For example, *degree centrality* simply measures the number of connections a *node* has to other nodes. In the example above, each member of the community would have a *degree centrality* of 2 because each member is connected to 2 other members of the community. Other 'flavours' of *centrality* measure such things as how crucial a member is in connecting sub-communities (*betweeness centrality*), or how connected his or her immediate neighbours are (*Eigenvector centrality*). This is a little bit like feeling more important because you are friends with someone else who is important.

Within a large social network, there are often highly connected sub-sets of members who are referred to as *communities* or *cliques*. A number of algorithms can be used to detect communities or cliques, but these are also highly dependent of user inputs and should be interpreted with caution. Hence, while it is a cliché to parse chiropractors into straights versus mixers, a user could generate as many sub-groups, i.e. *communities,* as they wanted to by toying with program settings.

It appears that the current study is the first time computer based social network analysis has been applied to the chiropractic research community. However, in other areas of health research, it has been used to identify key researchers and research themes. Analyses can also be extended in the time domain to see how networks, communities, individual researchers and research themes evolve over time. Social network analysis has also been used in other contexts to identify decidedly negative aspects of members, such as exploitive and destructive behaviours in criminal and political networks.

In the current analysis, our focus was on the macrostructure of research networks, not the qualities of individual members. However, as facility with Gephi is not that difficult to acquire, individual researchers may wish to use this, or a similar program, to develop and explore a more finely granulated analysis of their own immediate network.

Additionally, abstracts were aggregated into a single MSWord document and navigational sub-headings (introduction, methods, etc.) were removed. Typographical errors, spelling mistakes and rogue characters were removed to yield a final document with a word count of 193,226 words. The MSWord document was converted into a simple text document and analyzed with the WordList function of WordSmith Tools V6.0 (https://www.lexically.net/wordsmith/). After removing so-called 'function words' (eg. the, of, and), there was a total of 1,371 'content words' which occurred more than 20 times (an arbitrary threshold). Using the Keyword function of WordSmith Tools, a statistical comparison was conducted with a representative corpus of general American English, the New York Times sub-corpus, to identify keywords. Within linguistics, keywords are words which, within a particular sub-domain of the language, are statistically over-represented in comparison to their prevalence in general English. Keywords and their collocates (words located within 5 words left and right of the keyword in running text) provide some insight into the themes of published articles. The identification of themes within text, however, is a complex process for which there is no 'gold standard.' Thus, human interpretation of quantitative data introduces inevitable bias. Nonetheless, keywords and their collocates were also mapped in Gephi to visually demonstrate the relationships between presumptive themes. Thus, collocated terms were searched for the 25 most over-represented keywords. The relationships between these highly prevalent keywords and their collocated words were then mapped using Gephi. Specifically, the 25 core keywords were treated as 'sources' and the collocated terms were treated as 'targets'.

Results and Analysis

The results for the literature searches and filtering of articles are shown in the flowchart in figure 1. The PubMed searches for articles authored by CCRF-funded researchers returned 667 titles. The Pubmed search for articles attributed to CMCC returned 274 articles, while the office of research administration at CMCC provided records of 305 publications. The searches of the Index to Chiropractic Literature returned 1023 articles of which 164 had Canadian authors. When all searches were pooled and duplicates removed, 918 articles remained to be examined. Titles and abstracts were read by two researchers to eliminate papers which did not contain original data. After removing such articles (eg. editorials, commentaries and letters to the editor), 787 articles remained to be analyzed. It will be understood that some authors would have begun or ended their careers during the period covered by this study. Also, a number of non-chiropractor researchers would have been only transiently associated with chiropractic authors, and so the results contained herein would not be reflective of their entire careers. With these caveats, of 1961 authors in total, 339 had been corresponding authors within the time period and corpus of articles examined.

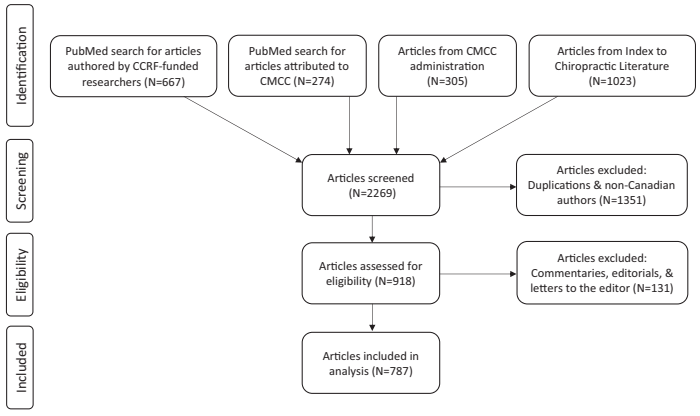


Fig. 1

Author-Coauthor Relationships

In figure 2, corresponding authors (who were not necessarily first authors or principle investigators) were plotted against their coauthors in Gephi using the ForceAtlas 2 algorithm, with the size of author nodes proportional to the number of publications on which each author appeared. Using the modularity function in Gephi, groups of authors who formed distinct communities or cliques were identified and are shown as distinct colours of nodes. Not surprisingly, and since coauthors tend to form teams and collaborate repeatedly, there are a number of distinct communities centred on authors with relatively high numbers of publications. Operator choices determine the number and size of communities identified within a network. However, with the parameters used in this study, there appear to be 5 main communities comprising, community 24 (purple), centred on author AU1386, community 13 (bright blue), centred on author AU0732, community 17 (grey), centred on author AU1117, community 14 (black), centred on author AU1652, and community 48 (red), centred on author AU0762. Interestingly, of the 20 authors with the highest number of recorded publications, 13 were in community 24. The remaining 7 of the 20 highest publishing authors were each located in separate communities. Community 24 also contained 3 authors who had never appeared as corresponding authors on any paper during the 6-year window of this study, but were named as coauthors on a relatively high number of papers. These authors and their numbers of publications were: AU0093 (26 papers), AU1425 (26 papers) and AU1175 (21 papers).

***Fig. 2** - Corresponding Author - Coauthor communities*

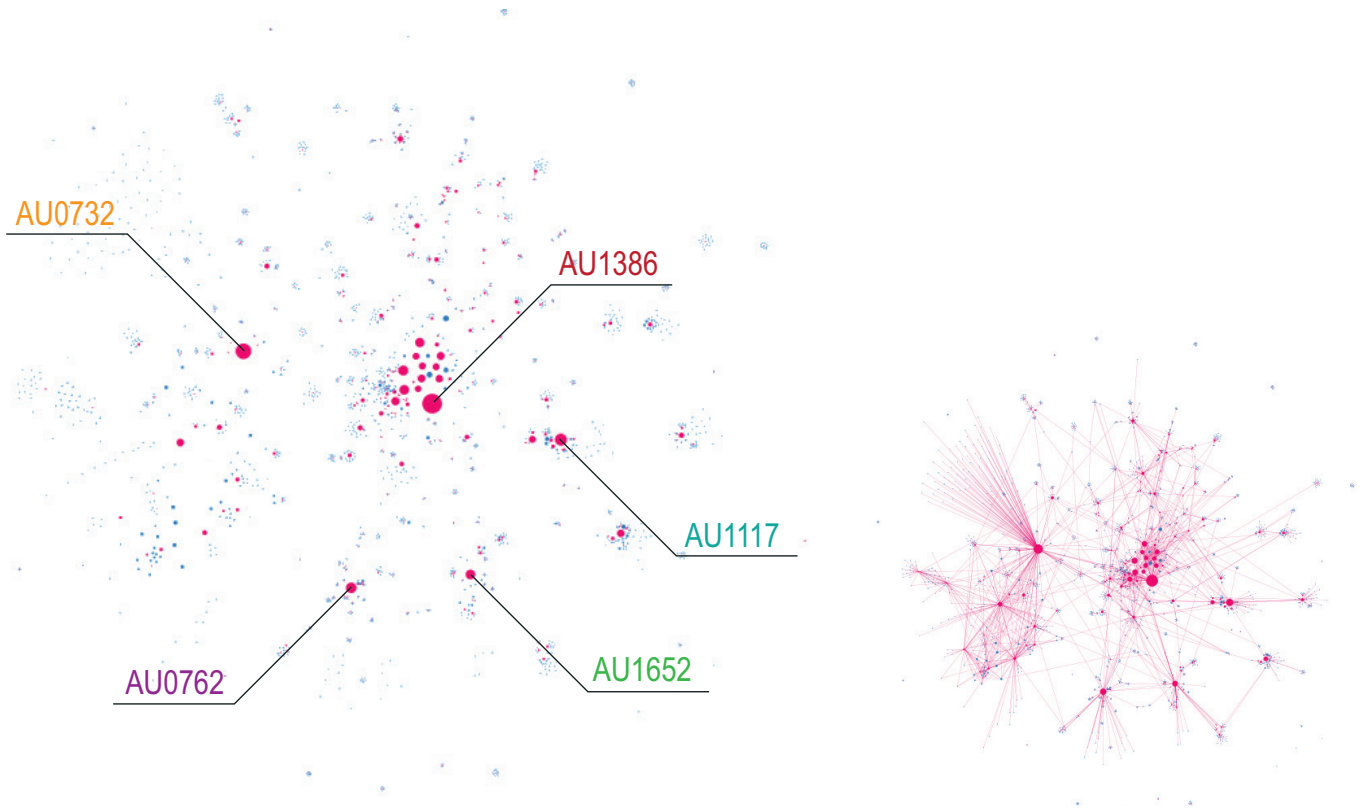


Fig. 3A & B - *Corresponding Author - Coauthor Networks, weighted by number of publications*

Further analyses of corresponding author – coauthor features are shown in figures 3A-3F with corresponding author nodes in red and non-corresponding author nodes in blue. In order to allow the reader to easily track authors through subsequent analyses, figure 3A displays the author network without edges – the vectors connecting corresponding authors to coauthors. Figure 3B (inset) presents the same results with edges included to demonstrate which corresponding authors are collaborating with which coauthors. Node sizes are weighted according to the number of papers on which each author appears.

In figure 3C, shown without edges for clarity, the size of author nodes is weighted according to attributable authorship. Using this statistic, an author who wrote a single paper with no coauthors would have the same measure of attributable authorship as each of 20 authors who collaboratively authored 20 papers. This therefore normalizes productivity to work time, if one assumes that all authors work essentially the same number of hours or days per year – likely not an unreasonable generalization for full-time researchers. With this caveat, a number of authors with relatively low numbers of total publications now emerge as quite efficient producers of research publications. These include authors AU0172 at 38%, AU1150 at 35%, AU0733 at 33%, AU1382 at 32%, and authors AU0692 and AU1662 both at 29%. All of these authors were full-time researchers or college/ university faculty members. Readers are invited to compare figure 3C with figure 3A. One will see that, interestingly, author AU1117, who had the second highest number of publications overall, also appeared among the top 20 authors in terms of attributable authorship at 23%.

Fig. 3C - *Corresponding Author - Coauthor Networks, weighted by attributable authorship*

This stands in contrast to author AU1386 who had the highest number of publications, but, at 7%, one of the lowest scores of attributable authorship.

In figure 3D, sizes of author nodes are weighted according to degree, which is the sum of all edges touching a node and so is a measure of connectedness within the network. In a social media network, members with a high measure of degree might be viewed as so-called 'influencers.' Within our network, these are the authors with the highest number of different coauthors. Author AU0732 again emerges as a significant member of the network, with authors AU1386 and AU1117 diminished because their connections are more constrained to their immediate communities.

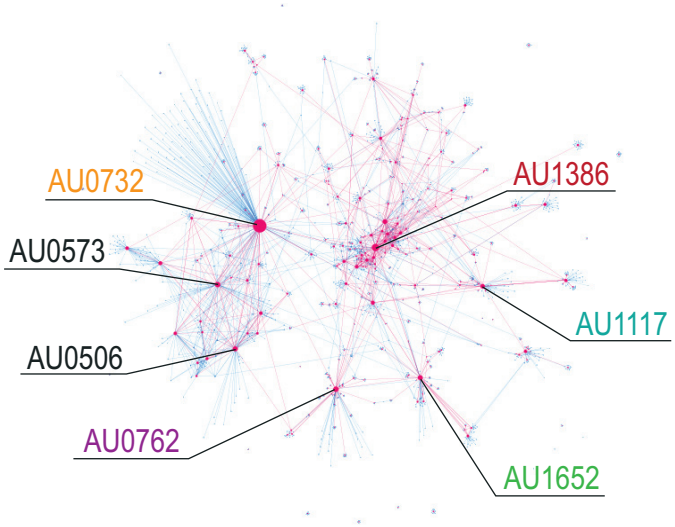


***Fig. 3D** - Corresponding Author - Coauthor Networks, weighted by degree*

Figure 3E weights author nodes according to betweeness centrality. Betweeness centrality measures the number of shortest paths between all pairs of nodes which pass through a reference node, with that divided by the number of all shortest paths in the network. In social networks, this is often a measure of the influence that a particular node actually exercises over a network. These individuals tend to be brokers of knowledge and power. Not surprisingly, the 5 authors with the highest number of publications were among the top 10 authors in terms of betweeness centrality. Of the top 5 authors in terms of betweeness centrality, 3 were members of community 24 (see figure 2), suggesting that the influence that they were exerting was largely within their close-knit community. The fifth highest ranked author (AU1652) seemed to function primarily as a methodologist, appearing on papers with disparate themes and designs, and so would have likely been brokering a very particular expertise.

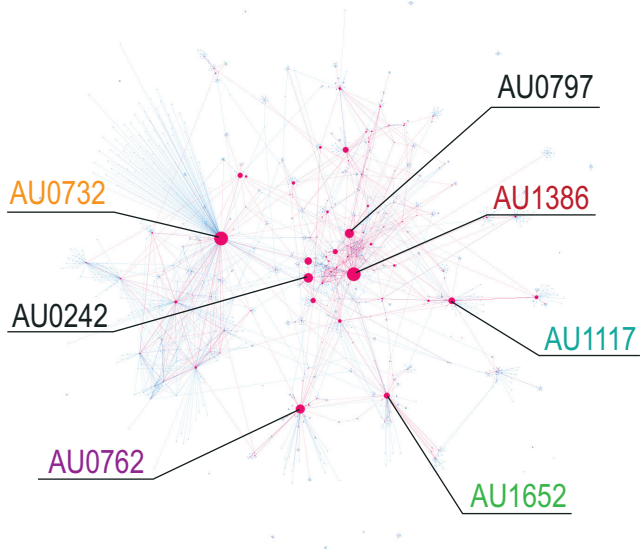


***Fig. 3E** - Corresponding Author - Coauthor Networks, weighted by betweenness centrality*

Figure 3F weights sizes of author nodes by Eigenvector centrality, which is also a measure of connectedness within a network, but weights each node according to the weight of the nodes to which it is connected. In other words, an author gains more centrality, which may mean some measure of importance, by being connected to other authors who also have more centrality or importance. Using this measure, community 24 now becomes a hub by virtue of members so consistently collaborating with one another and so seldom collaborating with authors outside of their immediate community.

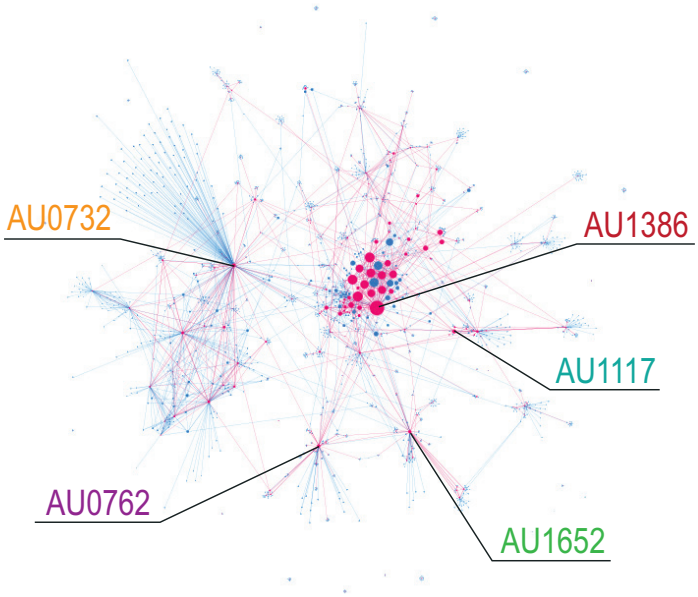


***Fig. 3F** - Corresponding Author - Coauthor Networks, weighted by Eigenvector centrality*

Author-Journal Relationships

Figure 4 shows the top 20 journals in our survey, ranked by number of published articles and with their corresponding journal impact factors. Two journals, the Journal of the Canadian Chiropractic Association (JCCA) and the Journal of Manipulative and Physiological Therapeutics (JMPT) emerged as the preferred instruments for publication and accounted for 204 (26%) of the 787 publications recorded. This demonstrates that a substantial minority of publications appeared in a journal either without an impact factor or with quite a small impact factor. Other preferred journals included BMC Chiropractic and Manual Therapies (40 publications), Spine (23 publications), Spine Journal (20 publications) and European Spine Journal (19 publications). Together, the top 6 journals accounted for approximately 40% of all articles in our corpus.

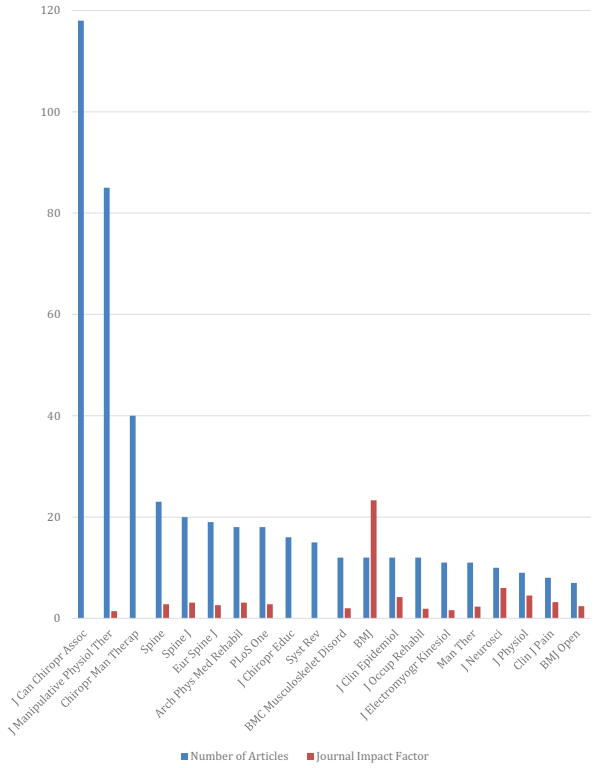


***Fig. 4** - Number of Publications versus Journal and Impact Factor*

Figures 5A and 5B show authors (red nodes) plotted onto their target journals (orange nodes). In figure 5A, author nodes are weighted according to the number of publications each author appears on, and journals are weighted according to the number of articles within our 2012-2017 corpus. Journals associated with the chiropractic profession and musculoskeletal care occupy a large area of the network and tend to cluster, illustrating a focus for chiropractic researchers. Basic scientific journals tended to be located peripherally indicating that their authors were not attracted to the clinical literature. In figure 5B, journal nodes are weighted by degree, meaning the total number of connections to all authors of all articles published in that journal. This again illustrates that the greatest amount of author output (authors x publications) is to a subset of journals with a chiropractic and clinical focus. In terms of betweeness centrality, a measure of influence within the network, the highest ranked journals, in descending order, were the JCCA, JMPT, Syst Rev, PLoS One, BMC Chiropr Man, Spine, J Clin Epidemiol, BMJ, J Occup Rehabil and the Cochrane Database.

When journals are weighted according to journal impact factor, as per figure 4, there is a disassociation between author output and impact factor. Indeed, the journal in our corpus with the highest impact factor, the New England Journal of Medicine, has such little association with chiropractic publishing that it could not be shown on these figures without expanding the scale many fold. Within chiropractic institutions, impact factor may still have some currency. However, the credibility of journal impact factor (JIF) as a measure of manuscript or journal quality has undergone substantial erosion in the past decade or so [10]. What was meant to be an objective, calculated measure of the usefulness of a journal within its particular sub-discipline, has now become a negotiated commodity, leading a number of critics to suggest alternative bibliometrics for authors, papers and journals [11-13]. Within a field with so few researchers and papers, in comparison to the greater enterprise of health research, impact factor has become almost meaningless, and chiropractic researchers seem to have made the decision that low- or no impact factor journals often constitute a more useful medium for communicating with their stakeholders.

Thematic Analysis

The 25 most over-represented keywords with their relative frequencies (in percent) in the chiropractic corpus versus the reference corpus of general English are shown in figure 6. Together with their most common collocates, these keywords were mapped in figure 7, with font scaled to the prevalence of each word in the chiropractic corpus. As one would expect, terms related to the processes of research were well represented; eg. study/studies, controlled, trials. Also, terminology associated with musculoskeletal pain and disability, and the patient were highly prevalent; eg. pain, patient(s), health, care. Biological

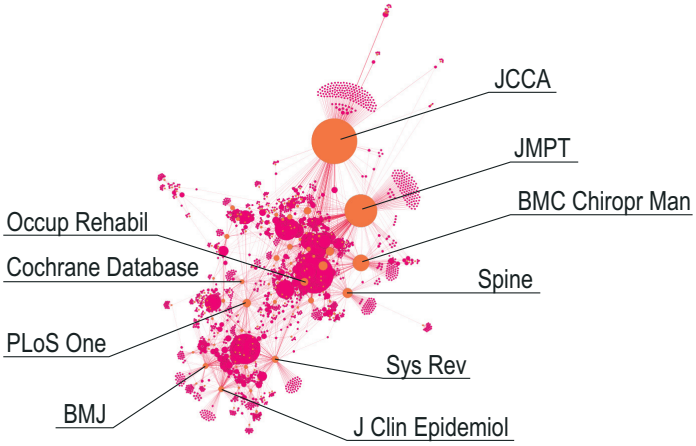


***Fig. 5A** - Author - Journal Networks, weighted by number of publications*

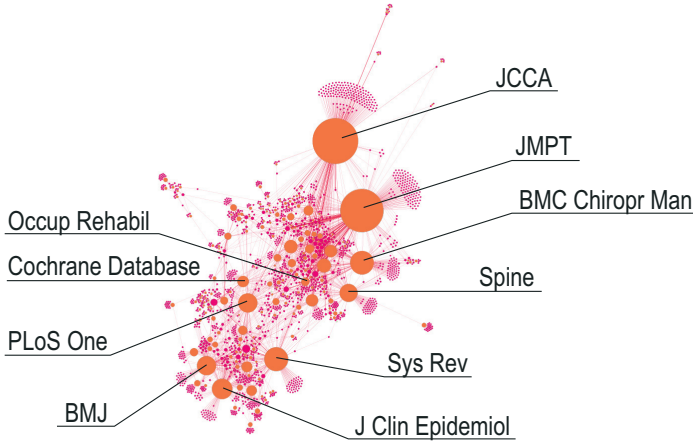


***Fig. 5B** - Author - Journal Coauthor Networks, weighted by degree*

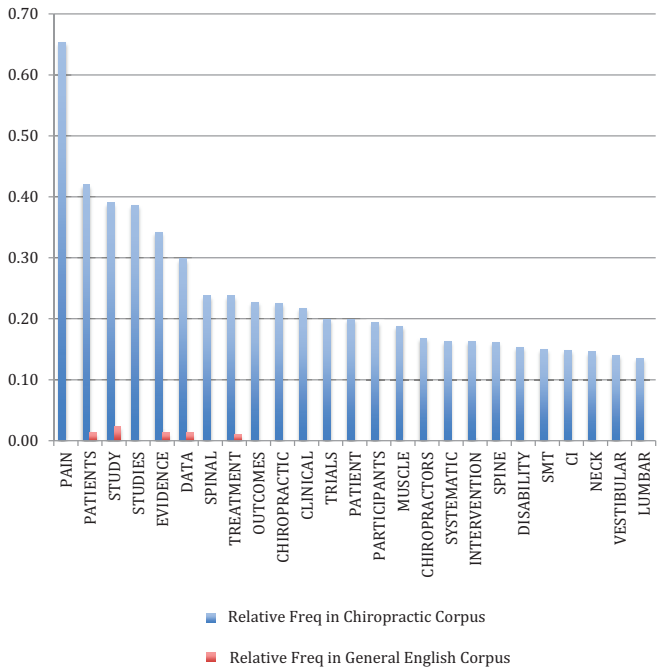


Fig. 6 - Keywords in Abstracts

terms, other than reference to the anatomy of the musculoskeletal system, were all but absent. These results are consistent with an earlier lexical analysis of chiropractic language, which revealed an emphasis on the clinical encounter and management of musculoskeletal disorders [14]. Nonetheless, of the 787 articles analyzed, a modest number appeared in journals which specialize in basic scientific research, including the Journal of Neuroscience (10 articles), Journal of Physiology (9 articles), Journal of Applied Physiology (3 articles) and Frontiers in Human Neuroscience, Molecular Pain, Neuroscience Letters, and the Journal of Physiological Science (2 articles each). Terms associated with teaching and learning were uncommon, although 16 articles in our corpus were from the Journal of Chiropractic Education.

According to our taxonomy, the greatest number of articles (30%) comprised reviews, meta-analyses and guidelines. These are genres which generally depend upon data generated by others, and do not involve the creation of new knowledge. Prospective clinical studies were relatively uncommon, accounting for only 4% of our corpus, and retrospective clinical studies, other than case studies and case series, made up 2%. Case studies and case series constituted 9% of the corpus. Surveys and epidemiological studies accounted for 12% of

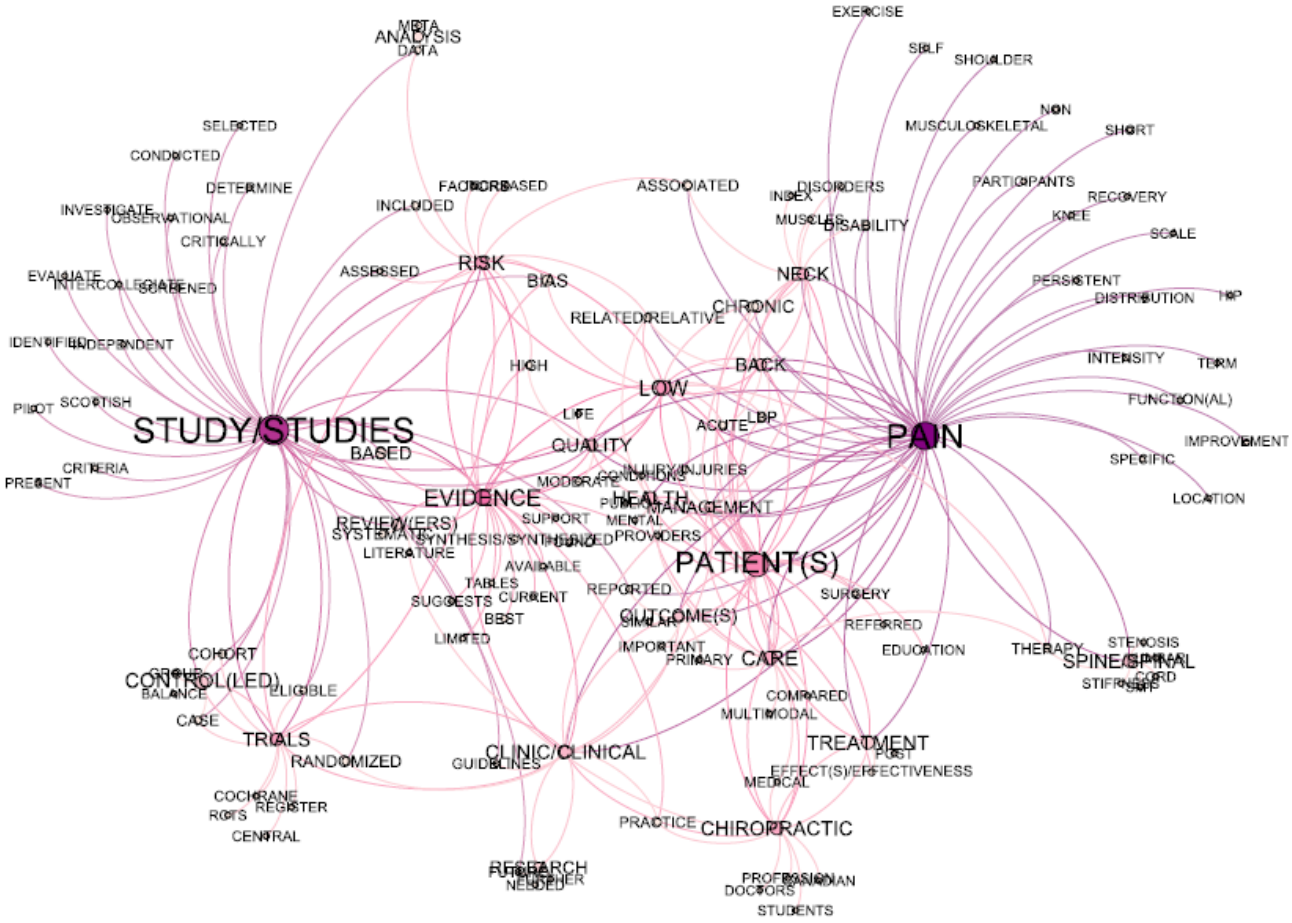


Fig. 7 - Keywords - Collocate Networks

papers. Studies of diagnostic and prognostic methods made up 5% of the corpus. Studies of research design comprised 9% of the corpus and included pilot studies and protocol papers. Interestingly, in light of the under-representation of biological terms in our lexical analysis, 22% of articles dealt with basic scientific research, particularly research in biomechanics and the neurosciences. While in other literature there may be some debate casting 'biomechanical' chiropractic versus 'neurological' chiropractic, in our corpus there was often a blending of these two sub-disciplines. This approach or perspective of researchers is consistent with a more scientific view of the subluxation as a biomechanical lesion with neurological implications [15]. Many of these papers had a clear clinical orientation, pushing up the representation of clinical and patient-oriented terminology in our lexical analysis, so that biological terminology may have been somewhat under-represented in our lexical analysis. Studies related to the role of chiropractic in society and the socialization of chiropractors, including through education, accounted for 7% of publications.

Funder-Author Relationships

Approximately 260 funding agencies were acknowledged, although 398 articles did not name any funding source. By and large, and based on the acknowledgements within articles, sources of funding could not be tied to specific authors. The most cited agencies were the Canadian Institutes of Health Research (CIHR) (134 publications), the Canadian Chiropractic Research Foundation (CCRF) (65 publications) and the Natural Sciences and Engineering Research Council (NSERC) (61 publications). The agencies with the ten highest numbers of citations are shown in figure 8.

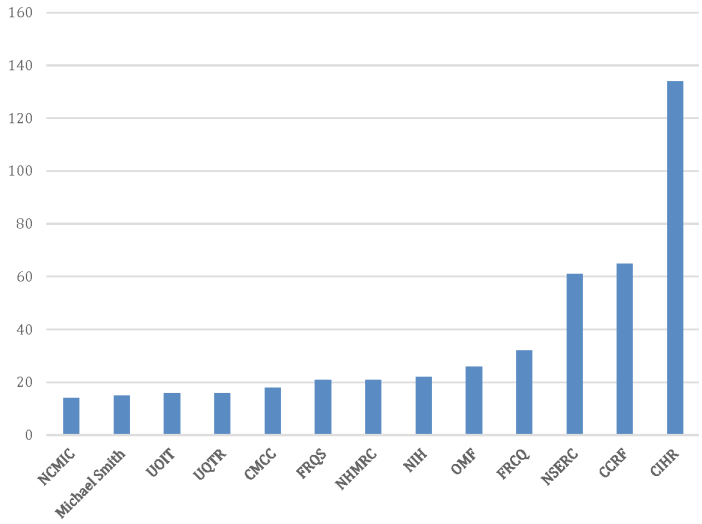


Fig. 8- Articles per Funding Agency

Another way of characterizing funding is to map funding agencies onto corresponding authors to see which authors 'attract' funding, allowing that the corresponding author might not be the actual principal investigator on an award. Figure 9 shows funding agencies (green nodes) mapped onto corresponding authors (red nodes) with size of nodes proportional to degree. The proximity of the CIHR, CCRF and NSERC suggest a high rate of co-funding of certain authors. Small groups of authors also show an affinity for funding agencies based in either the province of Quebec or the province of Ontario. In figure 10, using the same colour scheme and weighted by number of articles authored or funded, one can see a corona of unfunded authors around the core of funded authors and their agencies. It is interesting to see that some of these unfunded authors are quite productive, in terms of numbers of papers produced, despite the absence of financial support.

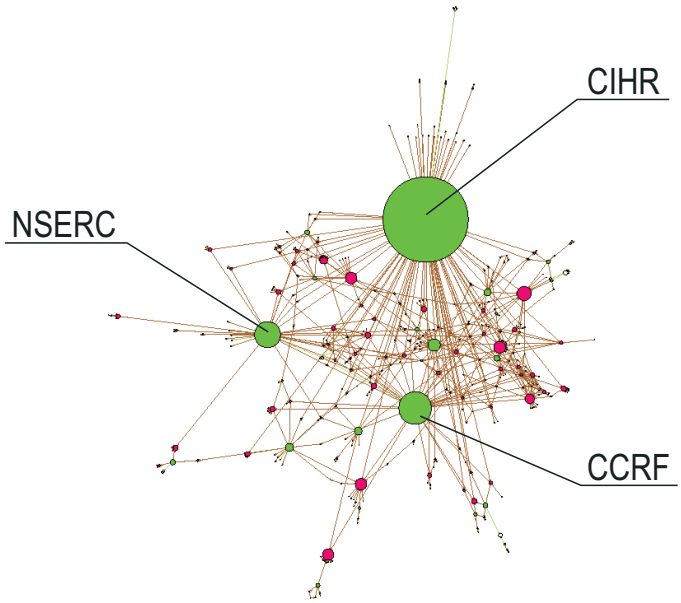


Fig. 9 - Funder - Corresponding Author Networks

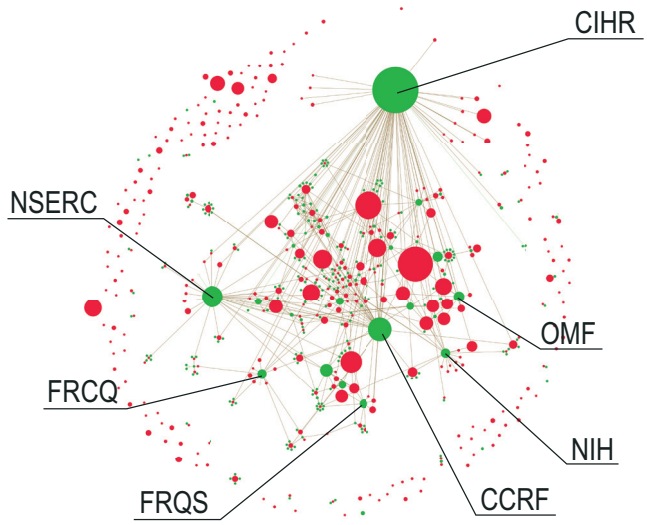


Fig. 10 - Funded and Unfunded Corresponding Author Networks, weighted by number of publications

Conclusions and Recommendations

Author-Coauthor Relationships

A significant challenge in correctly attributing authorship in this study was disambiguation of author names. Authors varied the number and even the order of their initials, and appeared to change names

with marriage. Additionally, in managing our database, there was a challenge with non-English characters being converted to rogue characters as we moved data through successive programs. The challenge of disambiguation could be mitigated if (i) authors would consistently record their names in one way and (ii) researchers and journals made more widespread use of unique author identifiers, such as Orcid identifier numbers (https://orcid.org).

Recommendation 1:

> Authors should adhere to a consistent format for their names throughout their careers, and should acquire and use unique author identifiers.

In the time period examined, a substantial volume of research relevant to chiropractic was published and these papers were authored by researchers both from within and outside of the chiropractic profession, testifying to an established pattern of inter-professional collaboration. Basically, researchers don't seem to care about pedigree. Their focus is on research quality and productivity.

Recommendation 2:

> In initiatives to foster inter-professional collaborations, other segments of the chiropractic profession might wish to consider giving a more central role to researchers who, it would seem, have an implicit sense of how to build collaborations and who may already have established pathways to parties to whom chiropractors are seeking access.

There does not appear to be one right pattern of behaviour for collaboration. Various authors have achieved successful careers working in relative isolation, working with a diversity of collaborators or working within what is effectively a closed clique. In this analysis, these models of behaviour were apparently successful for the principal investigators as they had all managed to establish careers in research and, by several measures, were productive. What is unclear is whether others, especially junior researchers, within their immediate communities benefitted from these dynamics. Structured mentoring can lead to quantifiable benefits for junior researchers [16, 17]. On the other hand, it is also apparent that junior investigators and their supervisors may have different expectations of their working relationship, and so may be pursuing goals which are, to a degree, at odds with one another [18].

Recommendation 3:

> 'Onboarding' of junior researchers should include a structured agreement which addresses the needs of both supervisors and junior researchers.

The data suggest that there are a number of persons identified as authors who likely do not meet the criteria suggested by the International Committee of Medical Journal Editors (see: http://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html). This is not a uniquely chiropractic challenge [19]. However, simply meeting the industry standard, as practised, should not provide consolation. Having said that, consideration should be given to research methodologists who contribute essential and specialized skills, but otherwise may not have an intellectual stake in a piece of work.

Recommendation 4:

> All persons identified as authors on chiropractic research publications should satisfy the criteria for authorship suggested by the International Committee of Medical Journal Editors.

Quantitative metrics of author output are a poor measure of the person and their work. For example, in this analysis the number of papers on which an author appeared did not correlate with their productivity, as measured by attributable authorship, nor, likely, with the quality of their work [20]. Indeed, in the arena of biomedical research in general, extreme numbers of articles published has been correlated with scientific fraud [21]. Metrics related to citation by peers reflect, to a degree, the impact of a paper within its niche, but do not speak to the societal benefit of the work, which may only become obvious many years after publication. Indeed, the 'metrification of quality' has become the bane of researchers who, by and large, must answer to administrators who may have little familiarity with the research enterprise [22]. It should be recognized that biomedical research serves a societal role. Researchers contribute to society at large by activities which contribute to the productivity of the research community, and which make research findings available to broader society. Analyses of centrality described above suggest that certain researchers function also as centres of cohesion in the research enterprise, and as brokers of knowledge and community power.

Recommendation 5:

> Consideration should be given to the use of valid quantitative and qualitative measures of the contributions of researchers to the research community and broader society.

Author-Article-Journal Relationships

Quite naturally, chiropractic researchers are overwhelmingly attracted to journals associated with the discipline of chiropractic and with clinically oriented aspects of spinal research. Such journals have relatively low or no impact factors, but this does not seem to influence authors' choices. Even authors who regularly publish in more prestigious journals also seek to publish in journals such as the Journal of the Canadian Chiropractic Association and the Journal of Manipulative and Physiological Therapeutics. One suspects that this represents a degree of self-sacrifice in the cause of communicating new knowledge to a wider audience in chiropractic. On the other hand, there is evidence that articles in low impact journals enhance an otherwise modest record of publication [23].

Recommendation 6:

> Journal impact factor should be disassociated from the evaluation of chiropractic journals, articles and researchers.

The bulk of articles were published in journals with a focus on musculoskeletal, particularly spinal, pain and disability. This conclusion is supported by lexical/thematic analysis of abstracts within our

corpus. This narrow clinical focus plays to a key clinical strength of the profession. On the other hand, much effort was devoted to the post-processing of research produced by others, thus generating an abundance of reviews, meta-analyses and guidelines. Relatively less effort was devoted to the generation of new clinical knowledge. Work pertaining to the neurobiological basis of chiropractic was substantial in terms of quantity and quality, and often referenced clinical issues. This contrasts with what may be the impression of some stakeholders that chiropractic practice is lacking in a robust scientific rationale. Apart from studies of chiropractic education, there were few papers dealing with the dynamics of the chiropractic community and its place in wider society.

Recommendation 7:

> Researchers should seek mechanisms to bring to stakeholders a balanced overview of the quality and quantity of research relevant to chiropractic. This could take the form of a peer-reviewed series of articles, a monograph or a continuing education initiative.

Recommendation 8:

> Entities involved in generating research agendas for chiropractic should consider whether the current balance of themes and genres addresses the questions which are most important for the profession and for the public which it serves.

Funder-Author Relationships

Disambiguation of funding agencies was an important challenge for data analysis in this study. Even the same corresponding author would find multiple ways to cite the same agency, and there was no apparent consistency concerning what level of a funding source to cite, eg. a provincial government versus a ministry within a provincial government versus an agency/programme within a ministry. Quite a large number of funding agencies provided support to chiropractic research. However, 3 agencies dominated the funding field: the Canadian Institutes for Health Research, the Canadian Chiropractic Research Foundation, and the National Engineering and Science Research Council. A number of articles acknowledged multiple funding sources, with several papers citing a dozen or more sources of funding. On the other hand, more than one half of all articles acknowledged no funding source. In some instances, it was clear that these papers were authored by researchers who were salaried to conduct and publish research.

Recommendation 9:

> Funding agencies and employers should instruct principal investigators in the appropriate format for acknowledging funding, and these formats should be followed consistently by authors and journals.

Limitations

Garbage in, garbage out – the current study made use of large amounts of data, and inevitably, with so much data, errors occur in gathering and processing. Some articles which would have met our inclusion criteria may have been overlooked, and others which did not meet our criteria may have been included in error. Beyond these technical challenges, the choice of variables to analyze, particularly with regard to statistics in network analysis, was rather arbitrary. A different choice of variables would have painted a different picture. Additionally, the data in this study were specific to Canadian chiropractic research and do not necessarily represent themes or research designs internationally. Finally, the authors' interpretations were necessarily subjective, and, considering the novelty of social network analysis of chiropractic research, should be taken with a grain of salt.

Future Research Questions

Based on this rather broad survey of the Canadian chiropractic research enterprise, more finely granulated studies may be warranted. For example, it may be useful to identify researchers with justified expertise in specific sub-domains of research. It may also be worthwhile to ask, for example, which communities spawn the most successful new, independent researchers, and therefore what mechanisms are most effective in sustaining the research enterprise. Similarly, the effectiveness of new initiatives, such as new collaborations, could be measured with meaningful metrics. Also, considering modern modes of research, limiting a study to the researchers of one country is decidedly artificial, and a more far-reaching examination would provide a more multidimensional analysis, while also bringing to light national and regional disparities.

References

1. Fries CJ. Classification of complementary and alternative medical practices: family physicians' ratings of effectiveness. Can Fam Physician. 2008;54(11):1570-1.
2. Polevoy T. Complementary medicine: risks to infants and children. Journal of Clinical Medicine. 2018;7.
3. Homola S. Pediatric chiropractic care: the subluxation question and referral risk. Bioethics. 2016;30(2):63-8.
4. McDowell T. Disappointing advertisement. Canadian Family Physician. 2009;55:868-9.
5. Cambell JB, Busse JW, Injeyan HS. Chiropractors and vaccination: a historical perspective. Pediatrics. 2000;105(4).
6. Simpson JK. Appeal to fear in health care: appropriate or inappropriate? Chiropr Man Therap. 2017;25:27.
7. Bussieres A, Terhorst L, Leach M, Stuber K, Evans R, Schneider MJ. Self-reported attitudes, skills and use of evidence-based practice among Canadian doctors of chiropractic: a national survey. J Can Chiropr Assoc. 2015;59(4):332-48.
8. Vernon H. The development of a research agenda for the Canadian chiropractic profession: report of the Consortium of Canadian Chiropractic Research Centres, November 2000. J Can Chiropr Assoc 2002;46(2):86-92.
9. Stuber K, Kawchuk G, Bussieres A. Research resource environment in Canada. Gathering knowledge in advance to inform chiropractic research priorities. J Can Chiropr Assoc. 2017;61(3):178-83.
10. Paulus FM, Cruz N, Krach S. The impact factor fallacy. Frontiers in Psychology. 2018;9:1487. doi: 10.3389/fpsyg.2018.01487.
11. Stringer MJ, Sales-Pardo M, Amaral LAN. Effectiveness of journal ranking schemes as a tool for locating information. PLoS One. 2008;3(2).

12. Bornmann L, Marx W. The journal impact factor and alternative metrics. EMBO reports. 2016;17(8):1094-7.
13. Liu XL, Gai SS, Zhou J. Journal impact factor: do the numerator and denominator need correction? PLoS One. 2016;11(3). doi: 10.1371/journal.pone.0151414.
14. Budgell BS, Kwong A, Millar N. A diachronic study of the language of chiropractic. J Can Chiropr Assoc. 2013;57(1):49-55.
15. Vernon H. Historical overview and update on subluxation theories. J Chiropr Humanit. 2010;17(1):22-32.
16. Libby AM, Hosokawa PW, Fairclough DL, Prochazka AV, Jones PJ, Ginde AA. Grant success for early-career faculty in patient-oriented research: difference-in-differences evaluation of an interdisciplinary mentored research training program. Acad Med. 2016;91(12):1666-75.
17. Spence JP, Buddgenbaum JL, Bice PJ, Welch JL, Carroll AE. Independent investigator incubator (I3): a comprehensive mentorship program to jumpstart productive research careers for junior faculty. BMC Medical Education. 2018;18. doi: 10.1186/s12909-018-1290-3.
18. Kaps L, Stine JG, Lemminger J, Vilarinho S. Great expectations: principal investigator and trainee perspectives on hiring, supervision, and mentoring. Hepatology Communications. 2018;2(9):999-1004.
19. Bhopal R, Rankin J, McColl E. The vexed question of authorship: views of researchers in a British medical faculty. BMJ Open. 1997;314. doi: 10.1136/bmj.314.7086.1009.
20. Altman DG. The scandal of poor medical research. BMJ. 1994;208. doi: 10.1136/bmj.308.6924.283.
21. Abma R. Scientific fraud and normal science. Science in Transition; November 7-8, 2013; Amsterdam, NL: Koninklijke Nederlandse, Akademie Van Wetenschappen; 2013.
22. Lorenz C. The metrification of quality and the fall of the academic profession. Oxford Magazine. 2015:7-11.
23. Donnelly K, McKenzie CRM, Muller-Trede J. Do publications in low-impact journals help or hurt a CV? J Exp Psychol Appl. 2019. doi: 10.1037/xap0000228.