Emerging Structure of Stem Cell Research in India: An Analysis of Publication Output, 1990-2014

Arpana Pandey and Pranav N. Desai

[1]*Centre for Studies in Science Policy, Jawaharlal Nehru University, New Delhi, INDIA-110067*

ABSTRACT

The potential of stem cell to change the face of medical treatment has brought it to the forefront of medical science in recent years. The present study analyzes the stem cell research output of India during 1990-2014 collected from the Scopus database. Some of the parameters used for analysis are publication output, publication share, growth rate, h-index, impact per paper, citation analysis, international collaboration and degree of collaboration, etc. The increasing significance of stem cell research was analyzed by ranking countries, institutions, authors, journals, etc. concerning total publication, their citation, and h-index. It is exciting to note that there has been notable growth in stem cell research publication from India. A total of 3964 papers were contributed by Indian authors during the study period, out of which 71.24% have been cited at least once and has a citation average of 9.27 citations per paper. Given the interdisciplinary and complex nature of the field, most of the research output is multiple authored and out of which more than one-third have internationally collaborated. The United States, which is the top most producing country, also the largest collaborative partner of India in stem cell research. The AIIMS and PlosOne are the most productive institution and journal respectively in this field.

Key words: Stem cell, Scientometrics, h-index and citation, Scopus.

INTRODUCTION

Stem cell research has been ascending to the forefront of medical science and public health in recent years. Stem cells are undifferentiated, totipotent[1] and pluripotent[2] cells that have two fundamental properties:the differentiation capability and ability to self-renewal. So, stem cells can be defined as cells that are capable of differentiating to give one or more types of mature bodily cells and of dividing to give further stem cells without the loss of differentiation potential.[1] The potential of stem cells as new tools for benefiting human health dwells in these twin properties that allow production of unlimited quantities of defined cell types.

Stem cells can be classified into three categories on the basis of their source, i.e., embryonic, Adult, and cord blood stem cells. The source of embryonic stem cells is early embryos. Adult stem cells are with limited potency and can be derived from adult body organs, e.g. Bone marrow, adipose tissues, cardiac tissues, etc. Stem cell could also be harvested from umbilical cord blood at the time of birth. An alternative method of obtaining stem cell is induced pluripotent stem cells (iPS cells). Through transcriptional reprogramming, somatic cells such as fibroblasts can be converted into iPS cells that resemble embryonic stem cells.

Stem cells are vital to the development, growth, maintenance and repair of our brains, bones, muscles, nerves, blood, skin and other organs. Stem cells have the potential

[a]Totipotent cells have total potential, i.e., capacity to form an entire organism. Totipotency is the ability of a single cell to divide and produce all the differentiated cells in an organism, including extra embryonic membranes.

[b]Pluripotent means the potential of a cell to differentiate into any of the three germ layers: endoderm, mesoderm, orectoderm. Pluripotent stem cells can give rise to any foetal or adultcell type. However, they alone cannot develop into a foetal or adult animal because they lack the potential to contribute to extraembryonic tissue such as the placenta.

***Address for correspondence:**
Arpana Pandey, Centre for Studies in Science Policy, School of Social Sciences, Jawaharlal Nehru University, New Delhi, INDIA.

E-mail: arpana.jnu@gmail.com.

Access this article online

Official Publication of

Phcog.Net
Bringing Medicinal Plants Researchers Together

Website: www.jscires.org

DOI: 10.5530/jscires.5.1.8

for medical treatment in the future. Any disease in which there is tissue degeneration may be the potential candidate for stem cell therapy, including the conditions and disabilities as Parkinson's and Alzheimer disease, spinal cord injury, stroke, burns, heart disease, diabetes, arthritis, liver disease, retinal regeneration, limb ischemia, hair cell regeneration, etc.[2]

The present study is based on the scientometric analysis of stem cell research output for the year 1990-2014. Publication to exchange research findings is an important aspect of science and is one of the basis of methods to evaluate scientific productivity. The yield of research activities by scholars or organizations are published in journals and being utilized and evaluated by other scholars. This practice makes a collaborative network among researchers. These articles have a unique capacity to discover knowledge patterns in the world. Different approaches have been used to identify knowledge patterns in articles, one of which is scientometric where different scientific areas are mapped using publication outputs as reflected in different databases. Studies have shown that mapped articles can provide a comprehensive representation of a scientific field. The Scientometric analysis is a method for analyzing scientific production and is a tool for evaluating the quality of scientific production. Scientific publications of countries, institutions, or journals in different areas have been evaluated using scientometric methods. The Scientometric analysis includes both quantitative description of research outputs and qualitative analysis using citation analysis. Citation analysis looks at the frequency of citations made to a paper in different sources. The number of citations demonstrates the scientific impact of a paper and quality of that paper using citation indices. However, pint-size research has been done to analyze the trends and quality of global stem cell research and the majority of these studies have been carried out in more developed countries. Therefore, it is imperative to have a clear understanding of the trends of information production in the field of stem cells in India so that researchers and policy makers could plan their future course of action accordingly.

As the study intend to examine qualitative and quantitative status of stem cell research in India in order to analyze its knowledge production patterns, the scientometric indicators used in this study are-

1. **Publication Output:** The global stem cell research output annually and number of publications per country that have at least one author affiliated with an institution in that country. A publication that is co-authored by authors from different countries thus counts toward the publication outputs of both countries.

2. **Global publication share:** The global share of publications for a particular country expressed as a percentage of the total output within the field of stem cells research. Using a global share in addition to absolute publication numbers provides insight by normalizing for increases in world publication growth and expansion of the field in question.

3. **Growth rate:** The compound annual growth rate is the mean annual growth rate over a specific period of time.

$$CAGR(t_0, t_n) = (V(t_n) / V(t_0))^{\frac{1}{t_n - t_0} - 1}$$

Here, V (t_o): start value,
V (t_n): finish value,
$t_n - t_o$: number of years.

4. **H-index:** Is a small number with a big impact, first introduced by J. E. Hirsh in 2005 with the aim to measure the cumulative impact of an author or institutions productivity by analysing the total citation received by their work.[3] Hirsch claims that the h-index is desirable to other single-number criteria, such as the total number of papers, the total number of citations and citations per paper because h-index pools an assessment of both quantity (number of papers) and quality (impact, or citations to these papers).[4]

5. **Impact Per Paper (IPP):** The IPP measures the ratio of citations in a year to scholarly papers published in the three previous years divided by the number of scholarly papers published in those same years. The IPP metric is using a citation window of three years which is considered to be the optimal time period to accurately measure citations in most subject fields. Taking into account the same peer-reviewed scholarly papers only in both the numerator and denominator of the equation provides a fair impact measurement of the journal and diminishes the chance of manipulation.[5]

6. **Citation analysis:** Citation analysis was considered an important indicator since the listing of references in publications is traditionally used by researchers to acknowledge the value of previous work.[6] The study used citation analysis to measure the impact of a publication or author by counting the number of times a paper is cited by other authors in their work.

7. **International collaboration:** In this study collaboration is inferred from publication co-authorship. A paper is considered an international collaboration if at least one of the authors is affiliated with an institution in a foreign country.

8. **Degree of collaboration:** The study implies the Subramanian's formula to determine the degree of collaboration among authors. His mathematical formula ascertained in calculating author's degree of collaboration in a discipline. The degree of collaboration among authors is the ratio of the number of collaborative publications to the total number of publication published in a discipline during a certain period of time.[7]

The degree of collaboration among authors can be measured mathematically as;

$$DC = Nm/Nm + Ns,$$

Where *Nm* is the number of multi-authored research papers in a discipline published during a period, and *N*s is the number of single-author research papers in a discipline published during the same period.

Previous Studies

Scientometrics is a widely used tool to analyze the literature around a research field. However, only a few scientometric studies have been conducted in the past on stem cell research publication. The most of these studies have been carried out in more developed countries and mostly to analyze the global trends in stem cell research. The earliest scientometric analysis of stem cell research is reported in 2003 on stem cell research productivity globally.[8] After that many scholars tried to analyze and map the global stem cell research field.[9-14].Various kinds of methods were used to map the stem cell research publication such as author co-citation analysis[9-10], co-word analysis[15,16] key-word plus[12,14] etc. The previous studies observed that stem cell field is highly multidisciplinary, with research ranging from biology to therapy, across all organs to a variety of diseases, and from biomedical sciences to social sciences and law. It is extremely fast growing and a sharp increase has been observed since 1991.[17] This field is characterized by its highly collaborative nature and number of scientific disciplines interrelated by stem cell research lends it an exciting yet complicated character.[9,18,13] There are few studies on the intellectual structure of stem cell research in developing countries.[19] and the only scientometric analysis of stem cell research in India has been conducted by Karpagam *et al*.[20] This study explores the trends in Stem Cell research in India during 1990-2014 using Scopus database. To analyze Indian's output of stem cell research several parameters like global publication share and rank, average citation per paper, authorship pattern, h-index, impact per paper, Degree of Collaboration, etc. were studied.

OBJECTIVE

The present study intended to explore of Stem Cells literature published during 1990-2014 as per the Scopus database and carry out the quantitative and qualitative assessment by way of analyzing various features of research output. In particular, the study focuses on the following objective:

1. To analyze the growth of global as well as Indian literature in stem cell research during the period 1990-2014.
2. To identify the countries with highest research output and India's collaborative research output with other countries.
3. To determine the type of publication, major subject categories and core journals in the field of study.
4. To identify the most prolific Indian authors, authorship pattern and degree of collaboration.
5. To evaluate the contribution of top Indian institutions and highly cited papers in stem cell research.
6. To analyze the quality and significance of research output using citation and h-index.

METHODOLOGY

For the purpose of the study, the Scopus (Elsevier) database (http://www.scopus.com) was searched to retrieve publications comprising stem cell research and limited the analysis to publications from 1990-2014, i.e., 25 years. The study selected Scopus for its size as it is the largest international multi disciplinary database of peer- reviewed literature.

The study used 'stem cell' as the search term, limiting this term to the occurrence in 'article titles, abstracts or keywords'. Study solely included papers published from 1990-2014, and the search was conducted within the four broad subject areas offered by Scopus: life sciences; health sciences; physical sciences and social sciences. For this study, all kind of published works was considered that are cited by and include references to other academic publication and are together referred to as 'paper' in this study.

A total of 324,175 publications were received from the Scopus database. The data was download and analyzed by using Microsoft Excel. H-index obtain from the database

has been used for evaluating performance measurement. Citation counts received by the papers have been used as a qualitative measure. The performance of institutions, authors, etc. has been judged on four parameters i.e. total publications, total citations, average citation per paper and h-index.

DATA ANALYSIS

This paper examines the stem cell publication landscape from 1990-2014. The study focused on the stem cells because of their clinical relevance and study examined publication data for all kind of stem cells, i.e., embryonic, adult as well as induced pluripotent stem cells. The analysis of data has been done with a view to measuring the growth of literature over the years, global publication share of top ten countries, publication type, research collaboration, authorship pattern, productivity viz. author-wise, institution wise and distribution of articles in journals and the impact factors of such journals.

Annual Publication output of Stem Cell Research

The global pattern shows rapid growth in stem cell research output. Between the year 1990 and 2014, a total of 324175 papers were indexed in Scopus database, with an average output of 12967 papers per year. The literature on stem cell gradually rose from 2718 papers in 1990 to 28834 papers in 2014, showing a gross increase of over 960% in this 25 year with a growth rate of 38.4% annually. This advance reveals activity in a broad range of subject areas, including life sciences, health sciences, physical sciences, social sciences and humanities related to stem cell research.

Analysis of the compound annual growth rate (CAGR), defined as the year-over-year constant growth rate over a specified period of time, shows exceptionally strong growth in stem cell research. Between 1990 and 2014, stem cell research publications grew by 9.91% per year. Thus, data indicates that stem cell research is a rapidly growing field. The Table 1 shows that the doubling time for absolute publications covered by the Scopus, taking 1990 as the base year, is six years. Publications covered by the Scopus increased by 50% in 1994 from that in 1990 whereas it took only two years to increase output by further 50% and from 2000 onwards, it took about four years to increase output by 50%. However, since last five years, from 2010 to 2014, there is only around 21% increase in global publication output.

The publication trends of annual papers in stem cell research from 1990 to 2014, shown in the Figure 1.

As Scopus has indexed 324,175 documents on stem cell research during 1990-2014 published globally, out of these, 3964 documents have been contributed by Indian authors. India's publication output increased from only

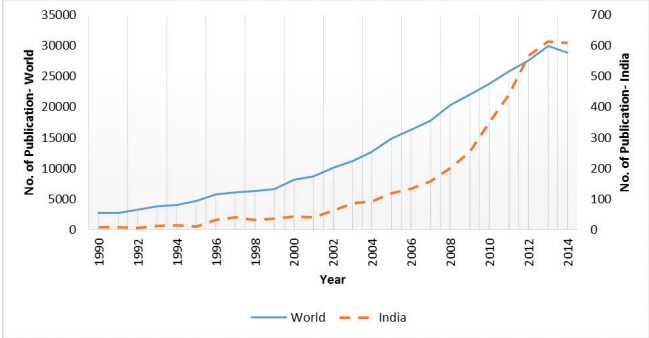

Figure 1: Growth of Literature in India and the World.
Source Scopus.

Table 1: Year wise publication output of stem cell research in India and World

Year	Number of Publications	
	World	India
2014	28834	610
2013	29951	613
2012	27621	568
2011	25840	440
2010	23783	350
2009	22075	254
2008	20301	200
2007	17851	158
2006	16283	133
2005	14829	118
2004	12738	92
2003	11141	87
2002	10060	61
2001	8692	40
2000	8146	42
1999	6632	36
1998	6307	31
1997	6129	41
1996	5753	31
1995	4669	11
1994	4076	15
1993	3778	12
1992	3243	5
1991	2725	8
1990	2718	8

Source: Scopus.

eight papers in 1990 to 610 papers in 2014, showing a growth rate of above 300% and CAGR of 18.93%. Indian publication data shows a rapid growth in publication output from 2005 onward. From the analysis of above data, study found that India has much more impressive growth rate (above 300%) compare to the world average that is 38.4 percent and compound annual growth rate of India in publication of stem cell literature is also more than double of the world average which shows that in India stem cell research is a fastest growing field.

Benchmarking research performance of the countries

The data analysis shows that the global publication share of top 10 most productive countries in stem cell research varies from 2.56% to 36.18% from 1990-2014. The United States of America is the most productive country. It has contributed the highest number of 117309 (36.18%) papers on stem cell research. The countries other than the USA, which has contributed the most of the papers on stem cell research are Japan 27007 (8.33%), Germany 26698 (8.23%), China 26031 (8.03%), United Kingdom 23612 (7.28%), and Italy 16405 (5.06%). The top productive counties in stem cell research are depicted in the Figure 2. India ranks 15th in stem cell research publication globally with a share of 1.22% of total stem cell publication. However, India shows the second highest growth rate in its publication share on stem cell research during the period studied which is 5277.08%, only behind the China with 19690.85% of increase rate during this period. Spain ranks 3rd in this growth rate with 2288.69% increase, followed by Italy (976.44%), Germany (961.47%), United Kingdom (666.64%), Netherland (636.59%), United States (622.66%), Japan (587.18%), Canada (571.24%) and France (490.52%). The publication data of top 10 countries and India, their total publication share and percent increase in published literature is given in the Table 2.

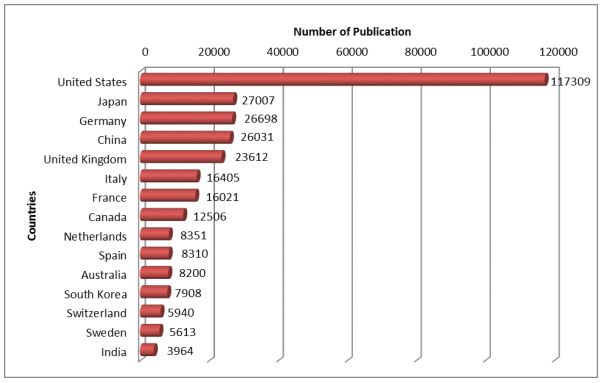

Figure 2: The contribution of top countries in stem cell research. **Source:** Scopus.

Collaborative research in stem cell area

Stem cell research is becoming increasingly interconnected, and international collaboration has shown many positive attributes such as enhancing the impact of research, bringing together a diversity of skills and solving a complex research problem.

India collaborated with 72 countries for research on stem cell. According to Scopus database, India has total 1539 collaborative research output during the period 1990-2014, which is 38.82% share of total publication output. Table 3 shows the top 20 collaborative countries on stem cell research. India's highest collaborative research is with United States of America (32.35%), followed by United Kingdom (6.49%), Germany (5.45%), Japan (5.26%), France (4.48%) and Australia (4.48%). India's top collab-

Table 2: Publication performance of top ten countries and India

Rank	Countries	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	Total	% of Publication	% increase in Publication
1.	U.S.A.	6591	11987	18786	32314	47631	117309	36.18	622.66
2.	Japan	1443	2923	5061	7664	9916	27007	8.33	587.18
3.	Germany	1015	2581	4495	7833	10774	26698	8.23	961.47
4.	China	85	210	1083	7831	16822	26031	8.03	19690.85
5.	U.K.	1262	2341	3675	6659	9675	23612	7.28	666.64
6.	Italy	692	1353	2302	4609	7449	16405	5.06	976.44
7.	France	992	2090	2846	4239	5854	16021	4.94	490.52
8.	Canada	772	1242	1893	3471	5128	12506	3.85	571.24
9.	Netherland	481	806	1225	2296	3543	8351	2.57	636.59
10.	Spain	168	650	1247	2232	4013	8310	2.56	2288.69
15.	India	48	150	322	863	2581	3964	1.22	5277.08

Source: Scopus.

Table 3: India's Collaborative Research Output with Foreign Countries in Stem Cell Research

S. No.	Country	1995-1999	2000-2004	2005-2009	2010-2014	Total Publication	% share of publication
1.	United States	12	33	89	364	498	32.35
2.	United Kingdom	3	4	23	70	100	6.49
3.	Germany	5	3	17	59	84	5.45
4.	Japan	3	3	18	57	81	5.26
5.	France	3		12	54	69	4.48
6.	Australia		1	10	58	69	4.48
7.	Canada	1	4	6	41	52	3.37
8.	Malaysia		1	3	44	48	3.11
9.	Italy	1	2	6	32	41	2.66
10.	Singapore	2		7	32	41	2.66
11.	South Korea			12	25	37	2.40
12.	Sweden		2	7	22	31	2.01
13.	China	2	2	2	25	31	2.01
14.	Switzerland			5	23	28	1.82
15.	Spain	1		3	23	27	1.75
16.	Taiwan		2	5	19	26	1.69
17.	Saudi Arabia		2		21	23	1.49
18.	Brazil			4	17	21	1.36
19.	Netherlands		2	3	16	21	1.36
20.	Belgium	1	1	3	12	17	1.10
20.	Israel			6	11	17	1.10

Source: Scopus.

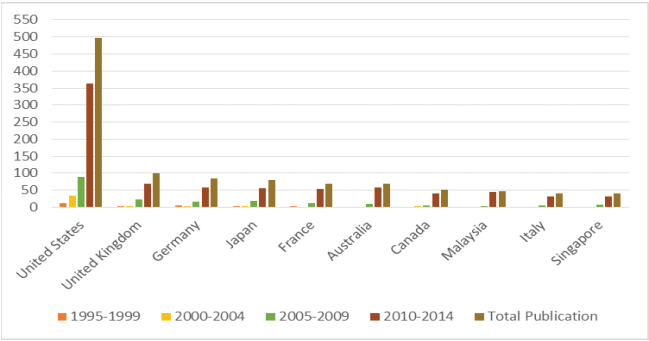

Figure 3: India's collaborative publication with major countries in stem cell research.
Source: Scopus.

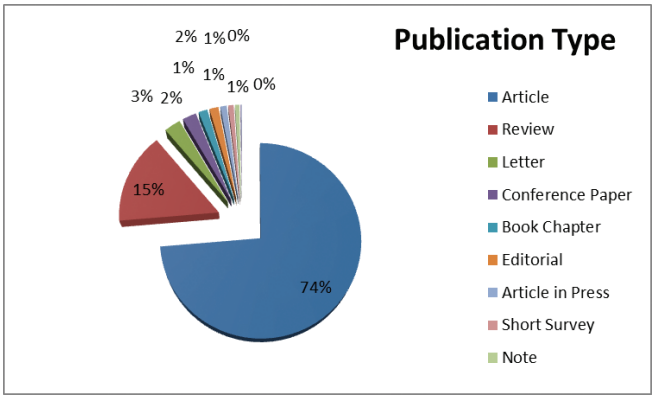

Figure 4: The share of different publication types in stem cell research.
Source: Scopus.

orative partners in the area of stem cell research has been provided in the Figure 3.

Bibliographic forms of stem cell research publication

From this study, 11 types of bibliographic form were found in a total of 3964 publications during the study period. Articles were the dominant document type, comprising 74% of the total production, followed by reviews (15%). Conference papers, letters, books etc. contributes very little to published literature on stem cells. Figure 4 showing the share of different bibliographic forms in stem cell research publication.

Table 4: Subject-wise break up of Indian publications in stem cell research

Subfields	TP	TC	ACPP	h-index
Medicine	2156	18,305	8.49	54
Biochemistry, Genetics and Molecular Biology	1,697	21,513	12.67	59
Pharmacology, Toxicology and Pharmaceutics	611	4558	7.45	32
Agriculture and Biological Sciences	458	4506	9.83	32
Immunology and Microbiology	230	2928	12.73	29
Neuroscience	228	3151	13.82	30
Chemical Engineering	226	2619	11.58	27
Engineering	212	2129	10.04	25
Material Science	162	2037	12.57	25
Chemistry	150	1699	11.32	22

TP= Total Papers, TC= Total Citations, ACPP=Average Citations per Paper.
Source: Scopus.

Stem cell research output in the context of different subjects

Based on the classification of subject categories of Scopus database, the publication output data of stem cell research is distributed in 27 subject categories during the last 25 years. The top ten productive subject categories are shown in Figure 5.

The subject categories containing atleast 100 papers are Medicine (2156), Biochemistry, genetics and molecular biology (1697), Pharmacology, toxicology and pharmaceutics (611), Agriculture and biological sciences (458), Immunology and Microbiology (230), Neuroscience (228), Chemical Engineering (226), Engineering (212), Material Science (162), and Chemistry (150). The Figure 5 shows that stem cell research is mainly located in the field of clinical research. The three most productive subject categories, which are mainly related to the clinical research and therapy, accounting for about 68% of the total published literature. With 2156 papers related to medicine, therapeutic research was holding primacy all through the study period.

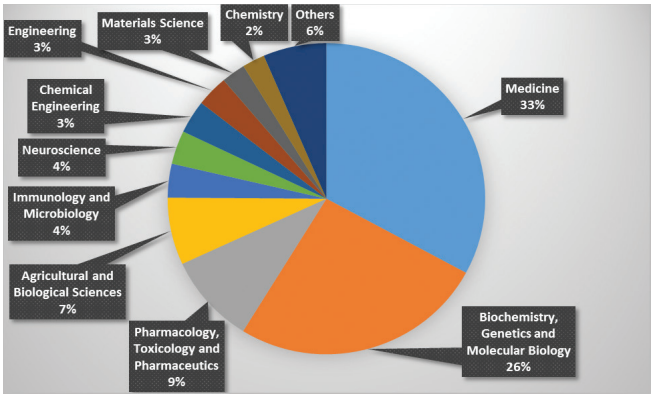

Figure 5: Major subject categories of stem cell research papers. **Source:** Scopus.

Among these subjects, biochemistry, genetics and molecular biology scored the highest number of total citations as well as h-index whereas, neuroscience scored the highest citation impact (13.82 citations per paper), followed by immunology and microbiology (12.73 citations per paper), Medicine (12.67 CPP), and material science (12.57 CPP). Table 4 has provided the details of major subject categories in stem cell research with their total publication, total citation, average citation and h-index.

Most Productive Journals

India's contribution to stem cell research has appeared in 158 national and international journals. The ten most productive journals publishing research papers on stem cell together contributes 402 papers, which accounts for 10.14% share of India's total output during 1990-2014. The analysis shows that there are 23 journals that have published 20 or more papers during the period of study that can be considered as most productive journals. Bradford law claimed that for a given subject area "there are a few very productive periodicals, a larger number of more moderate producers, and a still larger number of constantly diminishing productivity".[21] Bradford's Law of scattering describes a quantitative relationship between journals and the papers they publish. It explains that, only a small number of core journals will supply the nucleus of papers on a given topic which accounts for a substantial percentage (1/3) of the articles, to be followed by a second larger group of journals that accounts for another third, while a much larger group of journals picked up the last third.[22] The Bradford law explains that a few journals publish a relatively high percentage of the papers in a field, and there are many journals that publish only a few papers. The core journals in the field are most prolific, and other journals are with scattered papers.

Table 5: Most productive journals on stem cell research

S.No.	Journal	No. of Publication	IPP (2014)	h- index
1.	Plos One	90	3.27	153
2.	Indian Journal of Medical Research	42	1.719	55
3.	Indian Journal of Experimental Biology	42	1.075	51
4.	Indian Journal of Hematology and Blood Transfusion	38	0.438	6
5.	Stem Cells and Development	37	3.591	74
6.	Journal of Stem Cells	37	0.615	8
7.	International Journal of Pharma and Bio Sciences	34	0.411	11
8.	International Journal of Pharmacy and Pharmaceutical Sciences	28	0.609	20
9.	Journal of Association of Physicians of India	28	0.492	40
10.	Indian Journal of Pediatrics	26	0.664	34
11.	Indian Journal of Animal Sciences	24	0.213	14
12.	Indian Journal of Pathology and Microbiology	24	0.676	20
13.	Biochemical and Biophysical Research Communications	24	2.230	205
14.	Cell Biology International	23	1.670	56
15.	Neurology India	23	0.994	31
16.	Bone Marrow Transplantation	22	3.015	100
17.	Transplantation Proceedings	22	1.037	66
18.	Current Science	22	0.841	78
19.	Journal of Biosciences	21	1.871	50
20.	National Medical Journal of India	21	0.511	30
21.	Research Journal of Pharmaceutical Biological and Chemical Sciences	21	0.209	8
22.	Journal of Ethnopharmacology	20	3.345	129
23.	Medical Hypotheses	20	1.055	59

IPP= Impact per Paper.
Source: Scopus.

It is found that the Plos One (90) is the most productive journal followed by Indian Journal of Medical Research and Indian Journal of Experimental Biology, both with 42 publication in the period studied, followed by Indian Journal of Hematology and Blood Transfusion with 38 publication. Stem Cell and Development and Journal of Stem Cells both have published 37 papers each. The Stem Cells and Development had the highest impact with IPP of 3.591 and the journal Biochemical and Biophysical Research Communications had received the highest h-index of 205 among the top journals. Plos One, which is the most productive journal with the highest number of publication, rank second in terms of h-index (153) and third in terms of impact with IPP of 3.27. Interestingly, Journal of Ethnopharmacology, which is in 22nd place in terms of the number of publication, rank 2nd in terms of impact with IPP of 3.345 and 3rd in h-index (129). Journals that published atleast 20 or more papers related to stem cell research during 1990-2014 with their impact per paper (IPP) and h-index are listed below. The top most productive journals with their impact per paper and h-index has been provided in the Table 5.

Research profile of most productive Indian Institutions

One hundred and sixty Indian institutions are engaged in stem cell research and produced 3964 documents on stem cell research. Out of these, forty Indian institutions have contributed 25 or more papers. The top 20 most productive institutions in the area of stem cell research account for 34.23% of total publication output of India.

The study found that during the period 1990-2014, All India Institute of Medical Sciences (AIIMS) has been the most productive institution with 176 publications. It has contributed 4.36 percent of total Indian publications on stem cell research with citation count of 1235 and an average 7.02 citation per paper. After AIIMS, National Centre for Cell Science, Pune contributed 108 (2.72%) papers, followed by Postgraduate Institute for Medical

Table 6: Most productive institutions in India on stem cell research

Rank	Institutions	TP	Percentage	TC	ACPP	h-index
1.	All India Institute of Medical Sciences	176	4.36	1235	7.02	18
2.	National Centre for Cell Science India	108	2.72	2395	22.17	26
3.	Postgraduate Institute of Medical Education and Research	94	2.37	733	7.79	12
4.	Tata Memorial Hospital	93	2.34	835	8.97	14
5.	Christian Medical College, Vellore	82	2.06	879	10.72	17
6.	Manipal University Karnataka	81	2.04	965	11.91	17
7.	L.V. Prasad Eye Institute India	80	2.02	1363	17.04	23
8.	National Institute of Immunology, India	73	1.84	709	9.71	15
9.	Centre for Cellular and Molecular Biology, India	64	1.61	1056	16.5	18
10.	Sree Chitra Tirunal Institute for Medical Sciences and Technology	60	1.51	627	10.45	14
11.	Indian Veterinary Research Institute	56	1.41	288	5.14	7
12.	Indian Institute of Science	54	1.36	615	11.38	13
13.	Institute Rotary Cancer Hospital India	53	1.33	192	3.62	7
14.	Sanjay Gandhi Postgraduate Institute of Medical Sciences Lucknow	50	1.26	503	10.06	12
15.	The Maharaja Sayajirao University of Baroda	45	1.13	242	5.37	9
16.	Reliance Life Sciences	41	1.03	675	16.46	15
17.	National Dairy Research Institute India	38	0.95	236	6.21	9
18.	National Institute for Research in Reproductive Health India	38	0.95	353	9.28	11
19.	Tata Institute of Fundamental Research	36	0.91	1517	42.13	19
20.	Culcutta School of Tropical Medicine	35	0.88	118	3.37	7

TP= Total Publication, TC= Total Citation, ACPP=Average Citations per Paper.
Source: Scopus.

Education and Research (94 papers, 2.37%), Tata Memorial Hospital (93 papers, 2.34%), Christian Medial College (84 papers, 2.06%), etc. The average citation per paper of these top 20 institutions is 11.76. Among these top 20 institutions, only six institutions have higher ACPP than this group average. The highest impact of 42.13 citations per paper was scored by Tata institute of fundamental research, followed by National Centre for Cell Science (22.17), L.V. Prasad Eye Institute (17.04) and Centre for Cellular and Molecular Biology (16.5). The average h-index value of these top 20 organizations was 14.15 and nine Indian institutions have achieved higher h-index value than this group average. National Centre for Cell Science, Pune has the highest h-index of 26 followed by L.V. Prasad Eye Institute, Hyderabad with h-index value 23. Interestingly, The Tata institute of fundamental research which ranked 19th in terms of total publication output has highest average citation per paper (ACPP) with h-index score of 19 which is third highest in the group and All India Institute of Medical Sciences who holds the first position in total publication has very low average citation per paper.

A list of most productive Indian institutions, total citation received, average citation per paper and h-index value are given below in Table 6. Using publication data set, the study found that the top knowledge generating actors in India on stem cell research are either public research hospitals or government research institutes. Some private hospitals and research institutes are also actively engaged in this area of research, but universities are not playing a significant role in knowledge production in stem cell research.

Scientometric profile of most productive Indian Authors and Authorship pattern

The Table 7 below list the top 15 most prolific authors contributing to the stem cell research in India. They have contributed 541 papers thatconstitute 13.64% of total India publication. Ramesh Ramchandra Bhonde of School of Regenerative Medicine, Manipal University is the researcher with the highest number of papers (68) whereas Sangwan V. S. Singh of L. V. Prasad Eye Hospital, Hyderabad is the most cited author with 22.09 citations per paper and with highest h-index (20). Next top two authors with highest h-index are G.K. Vemuganti of University of Hyderabad and Ramesh Bhonde of Manipal University with h-index of 18. Geeta K. Vemuganti also has highest average citation per paper (ACPP) which is 22.58. Of these top 15 most productive authors, three are affiliated with Christian medical college, two- two with AIIMS, Manipal University, Calcutta School of Tropical

Table 7: Scientometric profile of India's top 15 authors in stem cell research

S.No.	Authors	Institution	TP	TC	ACPP	h-index
1.	Bhonde, R.	Manipal University, Karnataka	68	810	10.91	18
2.	Sangwan, V.S.	L. V. Prasad Eye Institute, Hyderabad	53	1171	22.09	20
3.	Kumar, L.	All India Institute of Medical Sciences, New Delhi	45	208	4.62	8
4.	Vemuganti, G.K.	University of Hyderabad, Hyderabad	39	881	22.58	18
5.	Trivedi, H.L.	Dr. HL Trivedi Institute of Transplantation Sciences, Ahmedabad	36	282	7.83	10
6.	Pal, R.	Manipal University, Karnataka	35	342	9.77	12
7.	Rajput, K.S.	Maharaja Sayajirao University of Baroda, Vadodara	34	188	5.52	8
8.	Vanikar, A.V.	Dr. HL Trivedi Institute of Transplantation Sciences, Ahmedabad	32	285	8.90	10
9.	George, B.	Christian Medical College, Vellore	31	413	13.32	12
10.	Srivastava, A.	Christian Medical College, Vellore	30	383	12.76	11
11.	Law, S.	Calcutta School of Tropical Medicine, Kolkata	29	108	3.72	7
12.	Bhartiya, D.	National Institute for Research in Reproductive Health	28	303	10.82	10
13.	Chaudhuri, S.	Calcutta School of Tropical Medicine, Kolkata	28	112	3.86	7
15.	Mohanty, S.	All India Institute of Medical Sciences, New Delhi	27	167	6.18	7

TP= Total Papers, TC= Total Citations, ACPP=Average Citations per Paper.
Source: Scopus.

Sciences and Dr. HL Trivedi Institute of Transplantation Sciences each.

Lotka's Law used to find out the frequency of publication by authors in a given field. The Lokta law states that "the number of authors making n contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that make a single contribution, is about 60 percent."[23] (Sudhier, 2013) This means that out of all the authors in a given field, about 60 percent authors will have just one publication and 15 percent will have two publications each ($1/2^2$ of 60), about 7 percent of authors will have three publications ($1/3^2$ times of 60), and so on. Further, according to Lotka's Law of scientific productivity, only six percent of the authors in a field will produce more than ten articles[24] (Patra and Chand, 2005). Lotka's Law, when applied to large bodies of literature over a fairly long period of time, can be accurate in general, but not statistically exact. The analysis reveals that the authorship pattern of Indian stem cell literature is not in conformity with Lokta's Law.

The year wise publication of data according to number of authors is presented in the Table 8. The analysis revealed that single authors contribute about 8% of the publications, and two-author contributions account for 17 percent, and rest of the research output (approx. 75%) is from multiple authors. Alternatively, it can be assumed thatthe stem cell researcher is in favor of team research. The interdisciplinary nature of research is one of the main reason behind the growing tendency towards multiple authorship in this field.

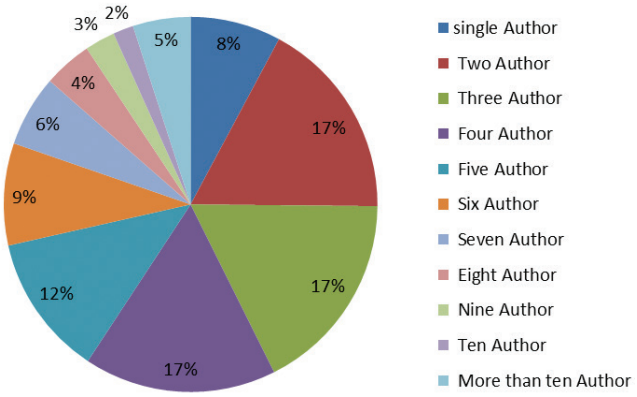

Figure 6: Authorship pattern in stem cell research in India.

The degree of collaboration among authors lies between 0.75 and 1.0. During the period of study, the share of multi-authored papers was around 92%. This demonstrates that the collaborative research is more predominant and productive in the field of stem cell research compare to single-author research, and the production of the single-author research isonly about 8%.

The diagram above (Figure 6) depicts the authorship pattern in the area of stem cell research. Three or more authors are foundin 75% of the publication records.

Highly Cited Indian Stem Cell Research Papers

The 3964 papers produced by Indian authors during the study period has been cited by 36,767 times in total. The average citation per paper and per year was 9.27 and

Table 8: Authorship pattern and degree of collaboration in Indian stem cell research publication

Year	Number of Authors													Degree of
Year	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten	More than ten	Total	More than one authors	collaboration
1990	1	2	4	1								8	7	0.875
1991		2	3	2					1			8	8	1
1992	1	2			2							5	4	0.8
1993	1	4	4	2						1		12	11	0.916
1994	2	4	4	2	1		2					15	13	0.866
1995	2	6	1	1		1						11	9	0.818
1996	3	9	7	4	5	2	1	1				32	29	0.906
1997	1	8	9	8	7	1	4	1	1		1	41	40	0.975
1998	2	11	7	4	2	1	1	1	2			31	29	0.935
1999	3	11	10	8	1		1	2				36	33	0.916
2000	3	10	11	4	4	3	3	1	2		1	42	39	0.928
2001	10	9	12	5		3	1					40	30	0.75
2002	11	10	12	9	3	7	3	2	2		2	61	50	0.819
2003	9	13	22	20	12	3	2	1	3	1	1	87	78	0.896
2004	14	21	24	15	10	2	3	1	1		1	92	78	0.847
2005	11	29	21	17	12	12	8	7		1		118	107	0.906
2006	21	28	20	14	17	10	11	5	2	2	3	133	112	0.842
2007	17	32	31	26	12	19	5	6	3	2	5	158	141	0.892
2008	25	35	32	30	27	19	7	4	6	1	14	200	175	0.875
2009	24	37	46	37	36	18	16	11	10	9	10	254	230	0.905
2010	34	57	69	63	38	23	17	11	11	7	20	350	316	0.902
2011	31	67	69	68	65	49	27	24	9	10	21	440	409	0.929
2012	25	93	96	108	77	56	34	19	16	14	28	566	541	0.955
2013	37	86	92	105	73	59	56	32	16	13	42	611	574	0.939
2014	23	100	87	107	80	61	42	37	19	9	44	609	586	0.962
Total	311	686	693	660	484	349	244	166	104	70	193	3960	3649	0.921

Source: Scopus.

1470.68 respectively. Further citation analysis reveals that out of 3964 papers on stem cell research, 2824 (71.24%) papers have been cited at least once. This also means that about 28.75% of these papers remained uncited throughout the years.

In total, only 30 papers had more than 100 citations, and 131 papers had 50 or more citations. The top 10 papers that were cited the most since 1990 are shown in Table 9. The table shows that multiple authors produce all the most cited papers.

FINDINGS

1. A total of 3,24,175 papers were indexed in Scopus database during the year 1990-2014, out of which Indian authors contributed 3964 papers.
2. Indian publication output increased from 8 papers in 1990 to 610 papers in 2014, witnessing an annual average growth rate of 18.93%.
3. The United States ranks as the top most country with maximum number of contributions followed by Japan and Germany as second and third positions respectively.

Table 9: Most cited Indian stem cell research papers

Title/ Authors	Journal	Year	Citations
A local Wnt-3a signal is required for development of the mammalian hippocampus *Lee, S.M.K., Tole, S., Grove, E., McMahon, A.P*	Development	2000	390
Concise review: Isolation and characterization of cells from human term placenta: Outcome of the First International Workshop on Placenta Derived Stem Cells *Parolini et al.*	Stem Cells	2008	381
Stem and progenitor-like cells contribute to the aggressive behavior of human epithelial ovarian cancer *Bapat, S.A., Mali, A.M., Koppikar, C.B., Kurrey, N.K*	Cancer Research	2005	328
Stem cells in postnatal myogenesis: Molecular mechanisms of satellite cell quiescence, activation and replenishment *Dhawan, Rando, T.A* J.,	Trends in Cell Biology	2005	230
Snail and slug mediate radioresistance and chemoresistance by antagonizing p53-mediated apoptosis and acquiring a stem-like phenotype in ovarian cancer cells *Kurrey et al.*	Stem Cell	2009	222
A draft map of human proteome *Kim et al.*	Nature	2014	190
Effect of trehalose on protein structure *Jain, N.K., Roy, I.*	Protein Science	2009	181
Human embryonic stem cells have a unique epigenetic signature *Bibikova et al.*	Genome Research	2006	177
Mesenchymal stem cells: Immunobiology and role in immunomodulation and tissue regeneration *Kode et al*.	Cytothyrapy	2009	175
A microwell array system for stem cell culture *Moeller et al.*	Biomaterials	2008	163

Source: Scopus.

4. India ranked 15th with its 1.22% of world publication share. However, India shows the second highest growth rate in its publication output stands only behind China.
5. International collaborative papers account for 38.82% of India's total output, of which the United States contributed the most, followed by the United Kingdom and Germany.
6. Among different bibliographic forms, article is the dominant type (74%), followed by reviews, latter, conference papers, etc.
7. The mainstream of stem cell research is therapy, biochemistry, genetics, molecular biology, pharmaceutics, etc.
8. As a flagship journal of the field, *PLoS One* published most of the papers, followed by *India Journal of Medical Research* and *Indian Journal of Experimental Biology*.
9. Among one hundred and sixty Indian institutions are engaged in stem cell research, study obtained *All India Institute of Medical Sciences* (AIIMS) the most productive institution in the country, whereas, *Tata Institute of Fundamental Research* has highest citation impact of 42.13 citations per paper and *National Centre for Cell Science*, Pune has the highest h-index of 26.
10. Most of the publications are multiple authored. Only 8% papers are single authored.
11. The study reveals that 71.24% of Indian papers on stem cell research have been cited at least once and has a citation average of 9.27 citations per paper.

CONCLUSION

This scientometric investigation of stem cell research papers has revealed some interesting finding of stem cell research in India. There is a rapid growth in stem cell research literature in last 25 years. Public research institutes and hospitals are more productive than private institutions. The study also showed that there is an increasing trend towards collaborative research in this field. The growing tendency of collaboration between researchers from different organizations and decline in single-author publications suggest the inclination of authors toward using capabilities of different institutes. It also seems that progress in the field of stem cells requires collaboration between a wide range of scientists from diverse fields.

The core journals indicate that researchers are selective in publishing their research results in highly specialized and high impact factor journals. However, majority researchers find Indian journals as an easier channel for publication of their research results. India's contribution to global research output is just about 1.22%, which is very low compared to other leading countries. Excellence in stem cell research is still confined to selected few institutions in the country despite wider institutional participation in the research. Given the growing importance of stem cell in regenerative therapy, it is necessary to put more focus on stem cell research. Government and other funding agencies should formulate policies to foster research and development in this area.

REFERENCES

1. Kumar S, Singh NP. Stem cells: A new paradigm. Indian Journal of Human Genetics. 2006 Jan 1;12(1):4.
2. Eggleson KK. Stem cell-based therapies: promises, obstacles, discordance, and the agora. Perspectives in biology and medicine. 2012;55(1):1-25.
3. Hirsch JE. An index to quantify an individual's scientific research output. Proceedings of the National academy of Sciences of the United States of America. 2005 Nov 15;102(46):16569-72.
4. Harzing, A. (2008) Reflections on the h-index. http://www.harzing.com/pop_hindex.htm. Accessed 15 July 2015.
5. Journal Metrics. Impact per Publication. http://www.journalmetrics.com/ipp.php. Accessed 21 July 2015.
6. Ugolini D, Parodi S, Santi L. Analysis of publication quality in a cancer research institute. Scientometrics. 1997 Feb 1;38(2):265-74.
7. Subramanyam K. Bibliometric studies of research collaboration: A review. Journal of information Science. 1983 Jan 1;6(1):33-8.
8. Ho Y, Chiu C, Tseng T, Chiu W. Assessing stem cell research productivity. Scientometrics. 2003 Jul 1;57(3):369-76.
9. Zhao D, Strotmann A. Counting first, last, or all authors in citation analysis: A comprehensive comparison in the highly collaborative stem cell research field.JASIST, 2011a;62(4):654-76.
10. Zhao D, Strotmann A. Intellectual structure of stem cell research: a comprehensive author co-citation analysis of a highly collaborative and multidisciplinary field. Scientometrics, 2011b;87(1):115-131.
11. Thirumagal A. Stem Cell Research: A Bibliometric Analysis from 1999-2008.Library Philosophy and Practice 2012.(e-journal), Paper 690.
12. Cantos-Mateos G, Vargas-Quesada B, Chinchilla-Rodríguez Z, Zulueta MA. Stem cell research: bibliometric analysis of main research areas through KeyWords Plus. InAslib Proceedings 2012 Nov 23 (Vol. 64, No. 6, pp. 561-590). Emerald Group Publishing Limited.
13. Luo J, Matthews KR. Globalization of stem cell science: an examination of current and past collaborative research networks. PloS one. 2013 Sep 12;8(9):e73598.
14. Lin CL, Ho YS. A bibliometric analysis of publications on pluripotent stem cell research. Cell Journal (Yakhteh). 2015;17(1):59-70.
15. Leydesdorff L, Hellsten I. Measuring the meaning of words in contexts: An automated analysis of controversies about'Monarch butterflies,''Frankenfoods,'and'stem cells'. Scientometrics. 2006 May 1;67(2):231-58.
16. An XY, Wu QQ. Co-word analysis of the trends in stem cells field based on subject heading weighting. Scientometrics. 2011 Apr 5;88(1):133-44.
17. Li LL, Ding G, Feng N, Wang MH, Ho YS. Global stem cell research trend: Bibliometric analysis as a tool for mapping of trends from 1991 to 2006. Scientometrics. 2009 Jul 1;80(1):39-58.
18. Ali-Khan SE, Ray M, McMahon DS, Thorsteinsdóttir H. Sino-Canadian collaborations in stem cell research: a scientometric analysis. PloS one. 2013 Feb 28;8(2):e57176.
19. Habibi S, Ahmadi M, Sedghi S, Hosseini F. Bibliometric Analysis of Stem Cell Publications in Iran. Acta Informatica Medica. 2014 Jul 1;22(4):259.
20. Karpagam R, Gopalakrishnan S, Babu BR, Natarajan M. Scientometric Analysis of Stem cell Research: A comparative study of India and other countries. Collnet Journal of Scientometrics and Information Management. 2012 Dec 1;6(2):229-52.
21. Bradford S.C, Egan M.E, Shera J.H. (1953). Documentation. 2nd ed. London, UK: Crossby Lockwood.
22. Nash-Stewart CE, Kruesi LM, Del Mar CB. Does Bradford's Law of Scattering predict the size of the literature in Cochrane Reviews?. Journal of the Medical Library Association. 2012 Apr 1;100(2):135-8.
23. Sudhier KP. Lotka's Law and Pattern of Author Productivity in the Area of Physics Research. DESIDOC Journal of Library & Information Technology. 2013 Nov 1;33(6):457-64.
24. Patra SK, Chand P. Biotechnology research profile of India. Scientometrics. 2005 Jun 1;63(3):583-97.

How to cite this article: Pandey A and Pranav N. Desai Emerging Structure of Stem Cell Research in India: An Analysis of Publication Output, 1990-2014. J Scientometric Res. 2016;5(1):49-61 Full text available at http://www.jscires.org/v5/i1