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DATAPAGE

Collaborative networks in gene editing

Over 15,000 articles and reviews published since 2000 were collected, with genome editing-related queries in the Web of Science (Table 1 and Supplemental Table S1). We use tech mining to investigate the underlying patterns that drive the adoption of genome editing, proposing an integrated research framework with bibliometrics, text analyses, and network analysis to analyze publication trends, authorship patterns, and key research topics and technologies of the genome editing field and provide quantitative and qualitative insights into the drivers of the CRISPR craze.

Of the literature on gene-editing modalities, CRISPR-Cas continues to grow, whereas publications describing meganucleases, zinc-finger nucleases, and transcription activator-like effector nuclease (TALENs) have been decreasing since 2016. The top 5 nations contributing gene-editing research are the United States, China, Germany, the United Kingdom, and Japan, with papers from China growing fastest.

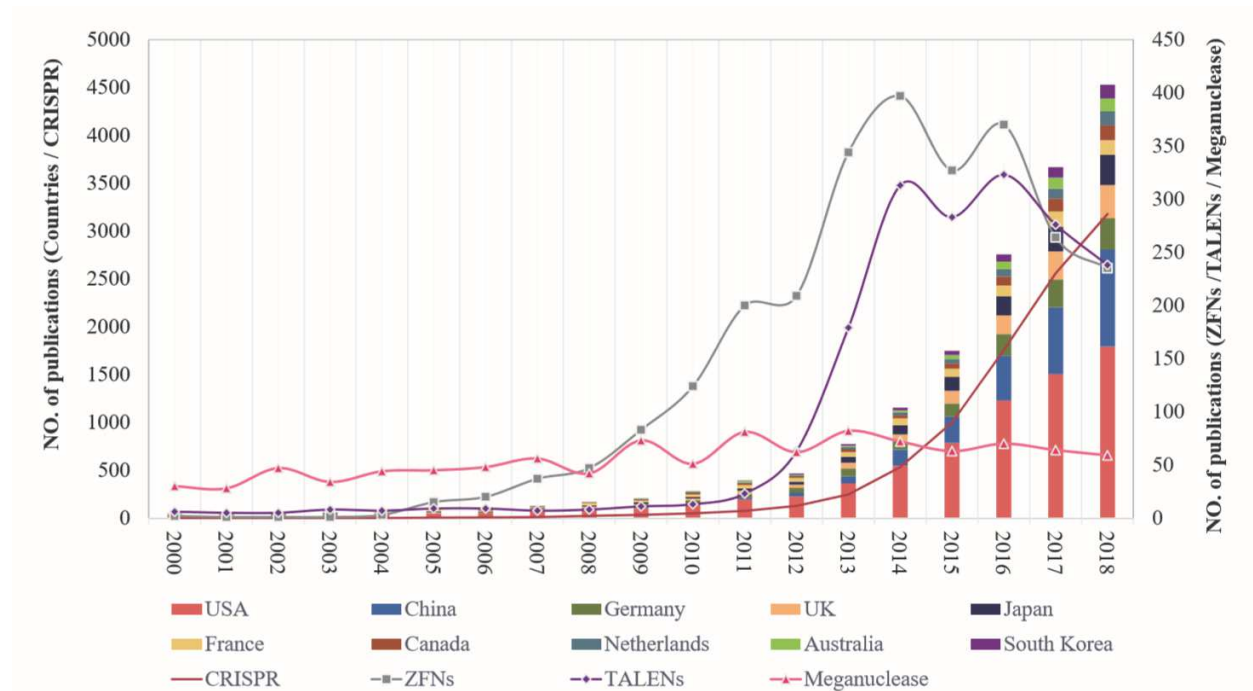
A diverse set of collaborative authors provides both leadership in the field and globalized contributions to the literature across space, time, and disciplines. The collaborative nature of this field is underscored by each of the 15 leading authors in the field (Table 2), all working with at least one fellow leading author, with 10 of the 15 co-authoring manuscripts with at least 2 other leading authors, and 4 highly collaborative authors contributing manuscripts with three or more prolific colleagues.

Table 1. Gene editing papers publish in Web of Science between 2000 and 2018 (updated March. 27, 2019). See Supplementary Table 1 for Methods

Component	Records (all types)	Records (research article and reviews)
Gene editing (General)	8,267	6,574
Meganucleases	1,153	1,051
Zinc finger nucleases (ZFNs)	3,074	2,680
Transcription activator-like effector nucleases (TALENs)	1,985	1,786
CRISPR-Cas	12,269	9,612
<i>Total</i>	<i>19,319</i>	<i>15,092</i>

Gene editing-related publications since 2000

CRISPR-Cas continues its meteoric rise in terms of papers.



Note that the number of publications relates to gene editing modality and top 10 countries with the largest number of authored/co-authored publications.

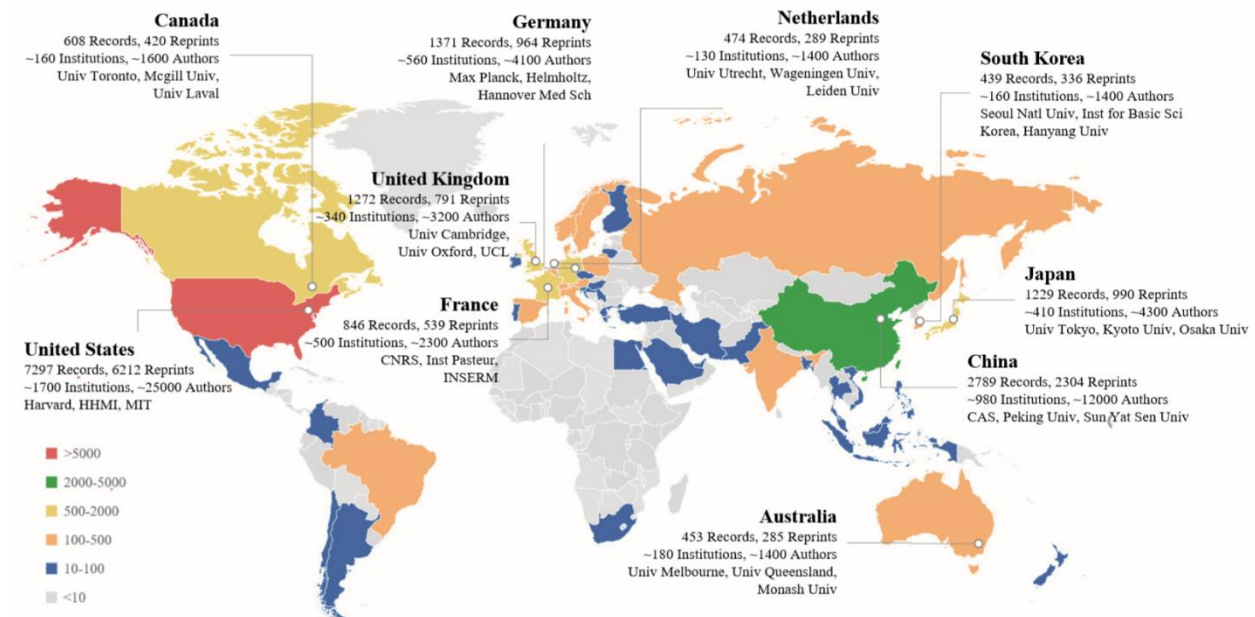
Table 2. Most prolific researchers publishing on gene editing

Rank	Researcher	Number of records	Organizations	Year range	Recent 3-Year Rate?	Top research fields [number of papers]
1	Feng Zhang,	105	Massachusetts Institute of Technology (MIT) [75]	2010 - 2018	50%	Multidisciplinary Sciences [34]; Biochemistry & Molecular Biology [30]; Cell Biology [22]
2	Takashi Yamamoto	91	Hiroshima University [91]	2008 - 2018	47%	Multidisciplinary Sciences [24]; Cell Biology [24]; Developmental Biology [16]
3	Jennifer A Doudna	85	University of California Berkeley [84]	2009 - 2018	53%	Multidisciplinary Sciences [37]; Biochemistry & Molecular Biology [29]; Cell Biology [25]
4	Jin-Soo Kim	81	Seoul National University [78]	2009 - 2018	52%	Biotechnology & Applied Microbiology [30]; Biochemistry & Molecular Biology [24]; Genetics & Heredity [19]
5	Tetsushi Sakuma	78	Hiroshima University [78]	2012 - 2018	44%	Multidisciplinary Sciences [22]; Cell Biology [21]; Developmental Biology [12]
6	Rodolphe Barrangou	77	North Carolina State University [50]	2007 - 2018	29%	Microbiology [36]; Biotechnology & Applied Microbiology [14]; Multidisciplinary Sciences [12]
7	Daniel F Voytas	74	University Minnesota Crookston [63]	2006 - 2018	42%	Plant Sciences [29]; Biotechnology & Applied Microbiology [17]; Multidisciplinary Sciences [17]
8	J Keith Joung,	72	Harvard University [72]	2006 - 2018	24%	Biotechnology & Applied Microbiology [20]; Multidisciplinary Sciences [13]; Biochemical Research Methods [13]
9	Philip D Gregory	71	Sangamo Biosci Inc [44]	2007 - 2018	11%	Biotechnology & Applied Microbiology [26]; Multidisciplinary Sciences [14]; Medicine, Research & Experimental [11]
10	Eugene V Koonin	67	Korea Centers for Disease Control & Prevention (KCDC) [39]	2006 - 2018	46%	Microbiology [19]; Biochemistry & Molecular Biology [19]; Biology [13]
11	Michael C Holmes	59	Sangamo Biosci Inc [32]	2007 - 2018	27%	Biotechnology & Applied Microbiology [20]; Medicine, Research & Experimental [19]; Genetics & Heredity [11]
12	Toni Cathomen	50	University of Freiburg [26]	2006 - 2018	22%	Medicine, Research & Experimental [21]; Biotechnology & Applied Microbiology [18]; Genetics & Heredity [17]
13	George M Church	50	Harvard University [50]	2010 - 2018	50%	Multidisciplinary Sciences [13]; Biochemical Research Methods [13]; Biochemistry & Molecular Biology [10]
14	Charles A Gersbach	46	Duke University [44]	2009 - 2018	50%	Biotechnology & Applied Microbiology [13]; Genetics & Heredity [12]; Biochemistry & Molecular Biology [11]
15	Barry L Stoddard	45	Fred Hutchinson Cancer Center [44]	2006 - 2018	16%	Biochemistry & Molecular Biology [33]; Multidisciplinary Sciences [8]; Cell Biology [8]

Note that 1) the recent 3-year rate is the proportion of the records published in the recent 3 years in the total number of the author's records. 2) The Web of Science assigns Subject Categories based on journals; there is overlap with some journals associated with more than one Subject Category.

Global geographical contributions to gene editing

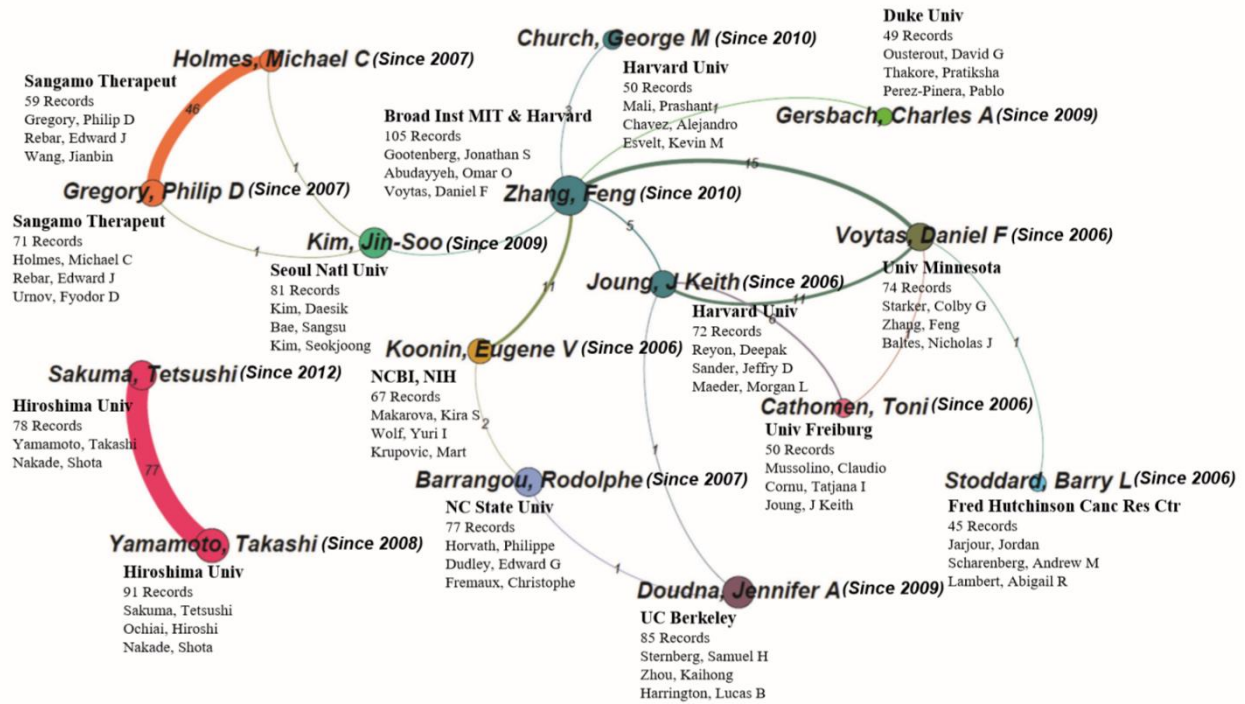
Leading countries and key research institutions of the gene editing research are profiling, indicating a global competition in the field.



Note that records represent the number of authored/co-authored articles, and reprints represent the number of articles published as the corresponding author.

Collaborative Patterns Between the 15 most Prolific Gene Editing Authors

Co-authorship patterns reveal a collaborative spirit triumphing over perceived competitiveness, in a field arguably infamous for fast pace and the individual pursuit of pioneering credit.



Note that the size of a node indicates the total number of records published by the related author, the weight of an edge represents the frequency of the collaborations between the two authors, and the collaborators listed under each node are the top three co-authors with the largest number of co-publications.

Ying Huang^{1,2}, Alan Porter^{3,4}, Yi Zhang⁵, Rodolphe Barrangou^{6*}

¹School of Information Management, Wuhan University, Wuhan 430072, China

²Centre for R&D Monitoring (ECOOM) and Department of MSI, KU Leuven, Leuven 3000, Belgium

³Search Technology, Inc., Norcross, GA 30092, United States

⁴Program in Science, Technology & Innovation Policy (STIP), Georgia Institute of Technology, Atlanta, GA 30332, United States

⁵Centre for Artificial Intelligence, Faculty of Engineering and Information Technology, University of Technology Sydney, NSW 2007, Australia

⁶*Department of Food, Bioprocessing and Nutrition Sciences, North Carolina State University, Raleigh, NC 27695, United States*

Correspondence should be addressed to rbarran@ncsu.edu

Supplementary Table 1. Search strategy for investigating gene editing in the Web of Science (updated March. 27, 2019)

Component	Search Strategy
Gene editing (General)	TS=((Genome OR Gene OR Genetic OR DNA) NEAR/2 Editing)
Meganucleases	TS=(Meganuclease* OR "Homing Endonuclease*")
Zinc finger nucleases (ZFNs)	TS=("Zinc Finger Nuclease*" OR ZFN*)
Transcription activator-like effector nucleases (TALENs)	TS=((Transcription* Activator* Like Effector Nuclease*) OR ((Genome OR Gene OR Genetic OR DNA OR RNA) AND (TALEN* OR (TALE* AND "Transcription Activator*"))))
CRISPR-Cas	TS=("Clustered Regularly Interspaced Short Palindromic Repeat*" OR CRISPR*)

TS =Title, Abstract and Keywords; Indexes=SCI-EXPANDED, SSCI

Supplementary Table 2. Gene editing-related records

NO	Document type	Records	Number	Document type	Number
1	Article	12209	10	Book Review	9
2	Review	2883	11	Retracted Publication	5
3	Meeting Abstract	2596	12	Early Access	4
4	Editorial Material	972	13	Retraction	4
5	Book Chapter	284	14	Data Paper	2
6	News Item	269	15	Bibliography	1
7	Letter	232	16	Biographical-Item	1
8	Proceedings Paper	147	17	Database Review	1
9	Correction	141	18	Reprint	1

Note: Our analysis focuses on published articles and reviews only.

Supplementary Table 3. Sub-technologies and leading countries publishing on gene editing since 2000 (see Global geographical contributions to gene editing)

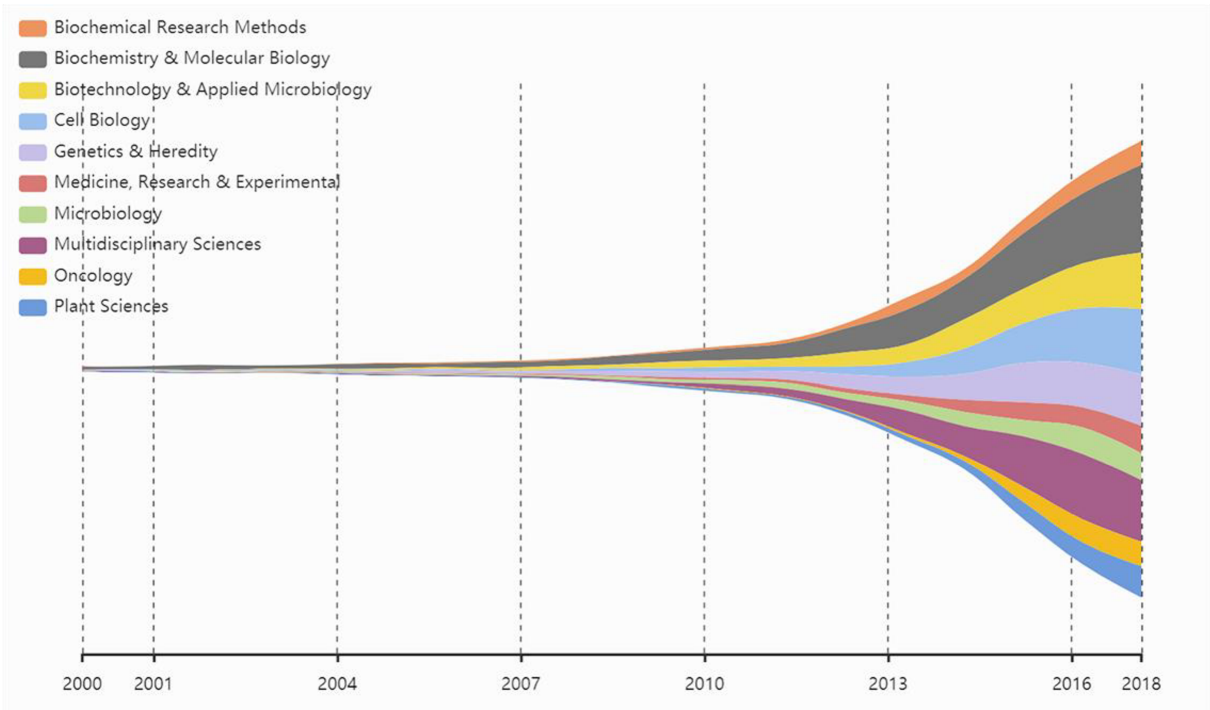
	Sub-technologies	Leading countries
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Year	CRISPR	ZFNs	TALENs	Meganuclease	USA	China	Germany	UK	Japan	France	Canada	Netherlands	Australia	South Korea
2000	0	2	6	30	22	1	9	6	2	6	2	1	0	0
2001	0	1	5	28	22	2	6	5	4	3	2	2	1	0
2002	1	1	5	47	30	2	11	5	6	7	1	1	0	0
2003	1	1	8	34	27	5	4	4	9	6	4	3	0	0
2004	0	3	7	44	39	0	7	8	2	6	3	0	0	0
2005	5	15	9	45	47	1	7	6	9	17	5	0	2	0
2006	7	20	9	48	57	1	12	10	5	16	6	2	3	0
2007	11	37	7	56	77	4	8	6	8	12	10	1	2	1
2008	24	47	8	42	84	4	16	16	13	24	7	1	4	1
2009	34	83	11	73	101	2	22	19	22	17	11	6	6	2
2010	49	124	13	51	144	13	28	20	17	26	18	10	6	2
2011	75	200	23	81	196	16	40	34	23	37	19	11	16	3
2012	128	209	63	62	227	38	52	32	30	41	14	9	10	13
2013	247	344	179	82	363	76	81	59	61	49	30	25	13	17
2014	532	397	313	72	548	166	88	72	98	71	32	31	19	29
2015	999	327	283	63	785	276	137	132	146	85	57	45	42	44
2016	1757	370	323	70	1229	469	225	196	202	110	94	78	79	74
2017	2560	264	276	64	1506	697	290	295	257	159	135	105	115	109
2018	3179	235	238	59	1793	1014	328	346	315	154	158	143	135	144

Supplementary Table 4. Leading US organizations publishing on gene editing

Institution	2000-2012	2013-2018	2000-2018	Recent 3-Year Rate	Top Research Fields
Harvard university	86	767	853	63.77%	Multidisciplinary Sciences [179]; Biochemistry & Molecular Biology [173]; Cell Biology [169]
Howard Hughes Medical Institute	54	420	474	60.55%	Multidisciplinary Sciences [149]; Biochemistry & Molecular Biology [125]; Cell Biology [118]
MIT	21	421	442	67.42%	Biochemistry & Molecular Biology [119]; Multidisciplinary Sciences [116]; Cell Biology [95]
US National Institutes of Health	52	364	416	62.98%	Biochemistry & Molecular Biology [102]; Genetics & Heredity [70]; Cell Biology [68]
University of California, Berkeley	44	252	296	56.42%	Multidisciplinary Sciences [79]; Biochemistry & Molecular Biology [72]; Cell Biology [63]
Stanford University	19	267	286	68.88%	Cell Biology [57]; Multidisciplinary Sciences [56]; Biochemistry & Molecular Biology [55]

US Department of Energy	44	196	240	50.42%	Biochemistry & Molecular Biology [60]; Multidisciplinary Sciences [58]; Biotechnology & Applied Microbiology [43]
University of California, San Francisco	18	221	239	70.29%	Biochemistry & Molecular Biology [59]; Cell Biology [51]; Multidisciplinary Sciences [48]
North Carolina State University	23	205	228	62.28%	Biochemistry & Molecular Biology [38]; Microbiology [37]; Multidisciplinary Sciences [34]
Washington University, -Seattle	64	162	226	56.19%	Biochemistry & Molecular Biology [64]; Multidisciplinary Sciences [36]; Medicine, Research & Experimental [34]



Supplementary Figure 1. Gene editing-related publications across scientific disciplines since 2000.

Note: scientific disciplines are based on the Web of Science Subject Categories.