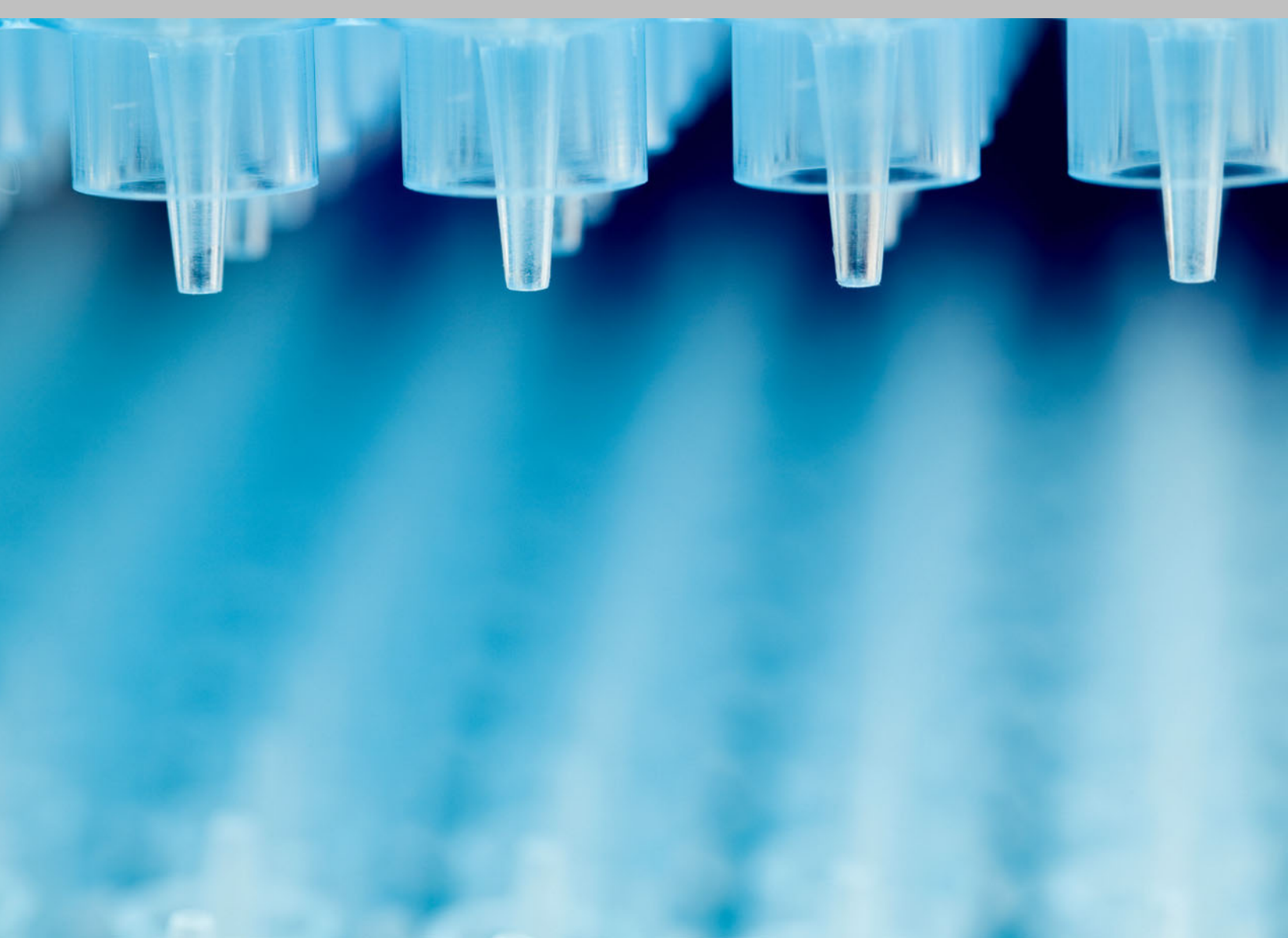


Science-Metrix

**Scientific Positioning of Alberta
in Health Research Specialties**



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Scientific Positioning of Alberta in Health Research Specialties

July 23, 2007

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Prepared for the
Alberta Heritage Foundation for Medical Research (AHFMR)

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Executive Summary

The Alberta Heritage Foundation for Medical Research (AHFMR) assists and funds health research with the aim of gaining knowledge applicable to the improvement of health outcomes in Alberta and throughout the world. In order to fund health research based on international standards of excellence, to build on Alberta's strengths in medical research and/or to foster research in areas of importance to the province, Science-Metrix was mandated by the AHFMR to produce a bibliometric assessment of Alberta's position in 11 strategic research specialties. These research areas were: Biochemistry, Cardiovascular System, Cell Biology, Genetics, Immunology, Microbiology, Oncology, Pediatrics, Pharmacology & Pharmacy, Physiology, and Surgery.

The present bibliometric analysis uses publications data retrieved from Thomson Scientific's *Science Citation Index* (SCI). A timeframe of 24 years (1982–2005) was divided into four six-year periods to outline the evolution of the scientific output at world, Canadian, and provincial levels. The performance of Alberta, leading Canadian provinces (British Columbia, Ontario and Quebec), and Canada is presented according to four scientometric indicators (number of papers, papers per capita, specialization index (SI), and average relative impact factor [ARIF]) and a combined multicriteria ranking. The analysis of trends in these indicators allowed conclusions to be drawn on the competitiveness, strengths, and weaknesses of Alberta in the 11 research areas. Data were also gathered on the most productive Albertan institutions and researchers, and on leading national and international collaborators.

In Alberta, Biochemistry came first among the 11 specialty fields in terms of absolute output, with 4,945 papers published between 1982 and 2005. Pharmacology & Pharmacy was next in importance with 2,571 papers. Similar results were observed at the Canadian and world levels, with these same specialties being the most active. Conversely, Pediatrics and Cell Biology were among the three fields with the lowest research activity at all levels.

In terms of output per capita, Alberta has performed better than the other leading provinces in 7 of the 11 specialties examined over the 24-year period. It was only surpassed by Ontario in Oncology, Pediatrics, and Surgery, and by BC in Genetics. From 1982 to 2005, Alberta has performed better than Canada as a whole in all specialties except Surgery. However, in the most recent period (2000–2005), it surpassed the Canadian average in all 11 specialties.

For the whole 24-year period, Alberta was specialized in 7 out of the 11 specialties considered. Alberta was mostly specialized in Physiology (SI of 2.12) and Microbiology (SI of 1.53) but was not specialized in Surgery (SI of 0.64) and Oncology (SI of 0.80). Over the four six-year periods, the SI of Alberta grew steadily in two specialties: Cardiovascular System (SI climbing from 0.43 in 1982–1987 to 1.60 in 2000–2005) and Physiology (SI from 1.32 to 2.70). The province is reducing its relative efforts in Genetics (SI from 1.54 to 1.17) and in Microbiology (SI from 1.73 to 1.30).

Compared to Canada and leading provinces, the impact of papers published by Albertan researchers between 1982 and 2005 was particularly high in Cardiovascular System (ARIF of 1.38) and Cell Biology (ARIF of 1.12). Notable performances were also obtained in Pediatrics (ARIF of 1.24) and Oncology (ARIF of 1.14). However, Alberta was lagging behind the world in Surgery and behind its Canadian counterparts, mostly in Genetics. While important increases in ARIF were seen for Alberta in Cell Biology and Oncology over the last four six-year periods, Cardiovascular System underwent one of the largest declines.

When considering the multicriteria ranking of selected provinces, Alberta emerged as an established leader in five specialties over the entire 1982–2005 period, namely Cardiovascular System, Cell Biology, Immunology, Microbiology, and Physiology. This performance was significantly better than the three other leading provinces, Ontario ranking first overall in three specialties, Quebec in two, and BC in one. Alberta was also in excellent position in Pharmacology & Pharmacy, having consistently ranked second over the four six-year periods and overall.

The leading role of Alberta in these six specialty fields should however be considered with caution. Indeed, its impact has declined between the last two six-year periods in all of these fields except Immunology, while its specialization

decreased in half of the six fields, namely Immunology, Microbiology, and Pharmacology & Pharmacy. Accordingly, Alberta should try to augment its relative output in Immunology, its impact in Cardiovascular System, Cell Biology, and Physiology, and both its output and impact in Microbiology and Pharmacology & Pharmacy in order to maintain and consolidate its leading position. The recent changes in the positioning of Alberta in three of the most active specialty fields in terms of absolute number of papers are also of concern. Biochemistry was still one of Alberta's main strength in 2000–2005 in terms of combined specialization and impact, but it lost ground against other Canadian provinces in the multicriteria ranking over the last two six-year periods. Similarly, Alberta's positioning has been deteriorating in Genetics and Oncology. While Alberta should mainly try to sustain the recent growth in impact in Biochemistry, it would need to direct serious efforts towards increasing its impact, and above all its output, to regain its leadership role in Genetics and Oncology.

Even though improvements were seen in Pediatrics, and even more so in Surgery, between 1982 and 2005, these two specialties represented Alberta's main weaknesses. To continue closing the gap with Canada and the world, Alberta should simultaneously increase output and quality, but more particularly should focus on its specialization in Pediatrics and sustain the recent growth in both specialization and impact in Surgery.

Among Albertan institutions, the University of Alberta was the most productive in terms of absolute number of papers published between 1982 and 2005 in most specialties, but particularly in Biochemistry, Immunology, Oncology, and Pharmacology & Pharmacy. The University of Calgary was especially dominant in Physiology. Among the other leading Albertan institutions, the most active are the Cross Cancer Institute, the Alberta Children's Hospital, the Tom Baker Cancer Centre, the University of Alberta Hospital, and the Foothills Medical Centre. With smaller number of papers than the Universities of Alberta and Calgary in most specialty fields, these non-academic institutions were often dominant in terms of specialization (which is easier when an organization has few papers overall) and sometimes dominant in terms of impact.

The top Albertan institution in terms of impact was the University of Calgary with an ARIF of 1.40 in Cardiovascular System. The University of Alberta was close behind with a 1.36 in both Cardiovascular System and Pediatrics. Other institutions that obtained high ARIFs with lower outputs include the Royal Alexandra Hospital in Pediatrics (ARIF of 1.64), the Foothills Medical Centre in Cardiovascular System (ARIF of 1.47), and the Cross Cancer Institute and the Tom Baker Center in Oncology (ARIFs of 1.24 and 1.21, respectively). Conversely, the outputs of all institutions involved in the field of Surgery were characterized by low specialization and impact.

Overall, 40 researchers from these different institutions have authored 20 publications or more in a single specialty between 2000 and 2005. In this group, 24 researchers were from the University of Alberta and 16 from the University of Calgary. A majority of these authors published their papers in the fields of Biochemistry (19) and Cardiovascular System (9). The top three leading authors were all from the University of Alberta and included Paul W. Armstrong with 106 papers in Cardiovascular System, Brian D. Sykes with 55 papers in Biochemistry, and Dennis E. Vance with 44 papers also in Biochemistry.

In all specialty fields except Oncology, Pediatrics, and Surgery, the inter-provincial collaboration rates of the University of Alberta were above their intra-provincial levels. By comparison, the University of Calgary was relatively less active in inter-provincial collaborations, with higher intra-provincial rates in 5 out of the 11 specialty fields. The top specialties for inter-provincial collaboration were primarily Biochemistry, Cardiovascular System, and Pharmacology & Pharmacy. The most frequent Canadian collaborators of Albertan institutions across the 11 specialty fields included the University of Toronto, the University of British Columbia, and McGill University. While the University of Alberta led in terms of absolute number of papers coauthored with foreign countries in 8 out of 11 specialties, the University of Calgary had higher collaboration rates in most fields. The Universities of Alberta and Calgary obtained their highest international collaboration rates in Cardiovascular System (49.8%) and Oncology (48.9%), respectively. Among the leaders in international collaborations, four foreign countries stood out, namely the United States, the United Kingdom, Japan and Germany.

Acronyms

AB:	Alberta
AHFMR:	Alberta Heritage Foundation for Medical Research
ARIF:	Average of relative impact factors
BC:	British Columbia
BCM:	Biochemistry
CVS:	Cardiovascular System
CLB:	Cell Biology
GEN:	Genetics
IMM:	Immunology
MCB:	Microbiology
NSE:	Natural sciences and engineering
ON:	Ontario
ONC:	Oncology
PED:	Pediatrics
PHM:	Pharmacology & Pharmacy
PHY:	Physiology
QC:	Quebec
SCI:	Science Citation Index
SI :	Specialization index
SUR:	Surgery
US:	United States

Contents

Executive Summary	i
Acronyms	iii
Contents	iv
Tables	v
Figures	vi
1 Introduction	1
2 Benchmarking of Alberta against Canada and selected Canadian provinces	2
3 Benchmarking of top institutions' in Alberta	10
4 Researchers	13
5 Scientific collaborations	16
6 Conclusion	21
Appendix A - Methods	23
Appendix B – Scientific output of BC, Ontario, and Quebec	26
Appendix C – Scientometric positioning	27
Appendix D – Inter-institutional collaboration networks	38

Tables

Table I	Number of papers in selected provinces, Canada and the world in 11 specialties, 1982–2005	2
Table II	Number of papers at the world, Canadian, and Albertan levels, in 11 specialties and by six-year period, 1982–2005	3
Table III	Average of yearly papers per capita (papers-year/10 ⁶ inhab.) for selected provinces, Canada, and the world in 11 specialties, 1982–2005.....	4
Table IV	Average of yearly papers per capita (papers-year/10 ⁶ inhab.) for selected provinces, Canada, and the world in 11 specialties and for the 2000 to 2005 period.....	5
Table V	Specialization Index (SI) by province in 11 specialties, 1982–2005.....	5
Table VI	Specialization Index (SI) of Alberta in 11 specialties and by six-year period, 1982–2005	6
Table VII	Average of relative impact factors (ARIF) by province in 11 specialties, 1982–2005	6
Table VIII	Average of relative impact factors (ARIF) of Alberta in 11 specialties and by six-year period, 1982–2005	7
Table IX	Multicriteria ranking of selected provinces comprising number of papers, papers per capita, SI, and ARIF, in 11 specialties, 1982–2005	8
Table X	Multicriteria ranking of selected provinces comprising number of papers, papers per capita, SI, and ARIF, in 11 specialties and by six-year period, 1982–2005.....	9
Table XI	Comparison of the output of the Universities of Alberta and Calgary based on the number of papers, SI, and ARIF (1982–2005)	10
Table XII	Comparison of the output of leading Albertan health centres and hospitals based on the number of papers, SI, and ARIF (1982–2005)	11
Table XIII	Comparison of the output of leading provincial and federal government institutions from Alberta based on the number of papers, SI, and ARIF (1982–2005).....	12
Table XIV	Albertan researchers with the most papers in one of the 11 specialties, 2000–2005	14
Table XV	Top ranking author in each specialty, 2000–2005	15
Table XVI	Collaborations of top Albertan institutions within Alberta in 11 specialties, rate and absolute number, 1994–2005.....	16
Table XVII	Collaborations of top Albertan institutions with other Canadian provinces in 11 specialties, rate and absolute number, 1994–2005.....	17
Table XVIII	Number of papers from Alberta authored in collaboration with researchers from other Canadian provinces in 11 specialties, 1994–2005.....	18
Table XIX	Collaborations of Alberta with top foreign countries in 11 specialties, rate and absolute number, 1994–2005	19
Table XX	Collaborations of top Albertan institutions with foreign countries, rate and absolute number, 1994–2005	20
Table XXI	Number of papers from BC, Ontario, and Quebec, in 11 specialties and by six-year period, 1982–2005	26

Figures

Figure 1	Scientometric positioning of provinces based on specialization and scientific impact in Biochemistry, 1994–1999 and 2000–2005	27
Figure 2	Scientometric positioning of provinces based on specialization and scientific impact in Cardiovascular System, 1994–1999 and 2000–2005.....	28
Figure 3	Scientometric positioning of provinces based on specialization and scientific impact in Cell Biology, 1994–1999 and 2000–2005	29
Figure 4	Scientometric positioning of provinces based on specialization and scientific impact in Genetics, 1994–1999 and 2000–2005.....	30
Figure 5	Scientometric positioning of provinces based on specialization and scientific impact in Immunology, 1994–1999 and 2000–2005	31
Figure 6	Scientometric positioning of provinces based on specialization and scientific impact in Microbiology, 1994–1999 and 2000–2005.....	32
Figure 7	Scientometric positioning of provinces based on specialization and scientific impact in Oncology, 1994–1999 and 2000–2005	33
Figure 8	Scientometric positioning of provinces based on specialization and scientific impact in Pediatrics, 1994–1999 and 2000–2005	34
Figure 9	Scientometric positioning of provinces based on specialization and scientific impact in Pharmacology & Pharmacy, 1994–1999 and 2000–2005	35
Figure 10	Scientometric positioning of provinces based on specialization and scientific impact in Physiology, 1994–1999 and 2000–2005.....	36
Figure 11	Scientometric positioning of provinces based on specialization and scientific impact in Surgery, 1994–1999 and 2000–2005	37
Figure 12	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Biochemistry, 1994–2005	38
Figure 13	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Cardiovascular System, 1994–2005	39
Figure 14	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Genetics, 1994–2005	40
Figure 15	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Immunology, 1994–2005	41
Figure 16	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Microbiology, 1994–2005	42
Figure 17	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Oncology, 1994–2005	43
Figure 18	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Pediatrics, 1994–2005	44
Figure 19	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Pharmacology & Pharmacy, 1994–2005.....	45
Figure 20	Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Physiology, 1994–2005	46

1 Introduction

The Alberta Heritage Foundation for Medical Research (AHFMR) assists and funds health research in order to generate knowledge and improve the health and quality of life of Albertans and people throughout the world. These initiatives are designed to support health research by individuals and organizations based on international standards of excellence and to build on Alberta's strengths in medical research and/or to foster research in areas of importance to the province. Within the context of its mission, AHFMR aims to acquire detailed knowledge on how Alberta's health research system compared to those of Canada and other leading Canadian provinces in targeted research areas between 1980 and 2005. To this end, AHFMR mandated Science-Metrix to benchmark Alberta's scientific output in 11 strategic research specialties:

- Biochemistry
- Cardiovascular System
- Cell Biology
- Genetics
- Immunology
- Microbiology
- Oncology
- Pediatrics
- Pharmacology & Pharmacy
- Physiology
- Surgery

Using bibliometric indicators primarily based on counts of scientific papers and citations to papers, Science-Metrix has positioned Albertan output in 11 research areas against that of selected Canadian provinces, namely British Columbia (BC), Ontario, and Quebec. In addition, this report provides an overview of leading Albertan institutions and cities in each specialty, as well as lists of the most active Albertan researchers during the last six years. Inter-institutional collaborations within Alberta and between Albertan institutions and other Canadian institutions and countries are also presented.

In Section 2, the scientific output of Alberta, selected Canadian provinces, and Canada are compared in terms of number of papers, number of papers per capita, specialization index (SI), and average of relative impact factors (ARIF). Based on these indicators, Alberta's output is also benchmarked against Canada and the selected Canadian provinces through scientometric positioning graphs and multicriteria rankings. Section 3 draws on bibliometric indicators to benchmark Albertan institutions in the different specialties, while Section 4 provides an overview of the most active Albertan researchers across these fields. In Section 5, leading collaborators of Alberta's institutions at the national (with institutions from other Canadian provinces) and international (foreign countries) levels are identified in terms of number of papers in each specialty, and collaboration networks of Alberta with leading Canadian institutions are analyzed. Finally, Section 6 examines the competitiveness, strengths, and weaknesses of Alberta's research, relative to its bibliometric performance, in all 11 strategic specialty fields and identifies areas in which it could be profitable for AHFMR to increase effort.

2 Benchmarking of Alberta against Canada and selected Canadian provinces

In order to benchmark Alberta's scientific output in each specialty field against that of Canada and selected Canadian provinces, four indicators (see Methods in Appendix A for details) were used: 1) number of papers; 2) number of papers per capita; 3) specialization index (SI); 3) average of relative impact factors (ARIF). This benchmarking is based on a 24-year period (1982–2005), which is broken down into four six-year periods in order to study the evolution in the selected fields.

In terms of absolute output, specialties had approximately the same relative importance at the Canadian and international levels. At the provincial level, Ontario dominated the Canadian landscape in absolute scientific output in all specialties. In general, the production of Alberta and BC were relatively similar. Still, Alberta was in third place in 8 of the 11 specialties, being surpassed by BC only in Genetics, Oncology, and Surgery (Table I). From 1982–2005, the highest number of papers from Albertan researchers among the 11 research areas selected were in Biochemistry (4,945 papers), followed by Pharmacology & Pharmacy and Immunology with 2,571 and 1,852 papers, respectively. Similar situations were observed at the Canadian and world levels, with these same specialties being the most active (Table I). The fields where activity was the lowest in Alberta were Pediatrics, Surgery, and Cell Biology, all having far less than 1000 publications during the same 24-year period.

Table I Number of papers in selected provinces, Canada and the world in 11 specialties, 1982–2005

Region	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
AB	4,945	1,080	665	1,277	1,852	1,376	1,120	382	2,571	1,498	569
BC	3,743	703	586	1,759	1,590	1,016	1,524	375	2,042	1,024	745
ON	14,204	3,679	2,406	5,026	5,304	3,499	5,365	1,662	7,166	4,093	4,186
QC	9,619	2,493	1,557	2,664	3,136	1,870	2,181	850	5,260	2,361	1,729
Canada	34,302	7,945	5,436	11,152	12,711	8,388	10,158	3,400	18,730	9,534	7,563
World	714,217	188,132	128,086	184,905	311,580	164,479	256,185	80,608	437,325	129,186	163,907

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

There was a constant increase at the world level in the number of papers from one six-year period to the next in all specialties except Pharmacology & Pharmacy and Physiology (Table II). Overall, while the world output more than doubled between the first and fourth periods in Genetics and Oncology, the fields of Cell Biology, Pediatrics, Pharmacology & Pharmacy, and Physiology only grew slightly. Likewise, there were increases in the scientific production of Canada in most specialties over all six-year periods but Canada's output in Pharmacology & Pharmacy and Physiology decreased between the last two periods after constant growth over the first three periods. Similar trends were also observed in Genetics and Immunology, while in Microbiology, the scientific output remained mostly

stable over the last three periods. Overall, Canada's output more than doubled in Cardiovascular System, Genetics, and Oncology between the first and fourth periods

Table II Number of papers at the world, Canadian, and Albertan levels, in 11 specialties and by six-year period, 1982–2005

	1982-1987	1988-1993	1994-1999	2000-2005	% of growth*
WORLD					
BCM	138,662	170,728	201,462	203,365	46.7%
CVS	35,223	44,045	51,503	57,361	62.9%
CLB	29,350	31,406	32,569	34,761	18.4%
GEN	28,539	41,891	56,203	58,272	104.2%
IMM	56,429	74,163	90,361	90,627	60.6%
MCB	31,401	39,129	44,140	49,809	58.6%
ONC	42,195	55,306	72,862	85,822	103.4%
PED	18,720	19,048	21,230	21,610	15.4%
PHM	101,175	111,755	112,355	112,040	10.7%
PHY	27,366	34,119	35,238	32,463	18.6%
SUR	32,684	34,622	45,433	51,168	56.6%
CANADA					
BCM	6,105	8,331	9,802	10,064	64.8%
CVS	1,047	1,595	2,136	3,167	202.5%
CLB	1,220	1,260	1,417	1,539	26.1%
GEN	1,520	2,654	3,497	3,481	129.0%
IMM	2,188	3,033	3,815	3,675	68.0%
MCB	1,722	2,218	2,165	2,283	32.6%
ONC	1,561	2,108	2,896	3,593	130.2%
PED	737	853	878	932	26.5%
PHM	4,428	4,802	4,825	4,675	5.6%
PHY	1,662	2,415	2,773	2,684	61.5%
SUR	1,722	1,800	1,977	2,064	19.9%
ALBERTA					
BCM	869	1,260	1,418	1,398	60.9%
CVS	72	181	293	534	641.7%
CLB	139	153	165	208	49.6%
GEN	212	310	359	396	86.8%
IMM	277	457	567	551	98.9%
MCB	261	368	371	376	44.1%
ONC	183	217	334	386	110.9%
PED	71	95	110	106	49.3%
PHM	530	666	685	690	30.2%
PHY	174	362	453	509	192.5%
SUR	80	129	144	216	170.0%

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 * Growth in output between the first period (1982-1987) and the most recent period (2000-2005)

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The output of Alberta declined slightly in 2000–2005 following constant growth over the first three periods in Biochemistry, Immunology, and Pediatrics (Table II). Increases in output between the first

and fourth periods were quite notable in at least four fields: in Cardiovascular System, the number of papers was multiplied by a factor of six; in Physiology, Surgery, and Oncology the output more than doubled. With decreases in outputs in seven specialties over the last two six-year periods, including consecutive drops between all four periods in Surgery, Quebec experienced the worst performance among selected provinces (Appendix B). Ontario did slightly better with decreases in six specialties over the four periods. However, two of these decreases were subsequently offset, either totally (Cell Biology) or partially (Microbiology), by output growth between later periods. As for BC, only two downturns were observed between consecutive six-year periods; one in Pediatrics, which was later offset by an increase in output, and the other in Physiology, which was observed between the last two six-year periods.

Over the last six-year period, Biochemistry and Pharmacology & Pharmacy were the predominant specialties in Alberta, and at the Canadian and world levels. Only in BC and Ontario was Pharmacology & Pharmacy replaced by other specialties in second position, namely Genetics in the former and Oncology in the latter (Appendix B). Taking into account the population size often provides a better understanding of the relative efforts of smaller entities when analyzing scientific output. For example, Alberta, which is the least populous province among that considered, ranked first in output per capita, with an average of about 75 papers per year per million inhabitants in Biochemistry (Table III), while it ranked third in absolute output in the same specialty.

From 1982–2005, Alberta has performed better than the other leading provinces in 7 of the 11 specialties examined. It was only surpassed by Ontario in Oncology, Pediatrics, and Surgery, and by BC in Genetics. In addition, Alberta has performed better than Canada as a whole in all specialties except Surgery (Table III).

Table III Average of yearly papers per capita (papers-year/10⁶ inhab.) for selected provinces, Canada, and the world in 11 specialties, 1982–2005

Region	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
AB	75.09	15.61	10.09	19.28	27.92	21.00	16.72	5.80	39.34	22.35	8.47
BC	42.69	7.81	6.77	19.73	17.88	11.68	17.05	4.32	23.91	11.88	8.59
ON	54.73	13.84	9.39	19.17	20.40	13.71	20.33	6.43	28.05	15.72	16.27
QC	55.86	14.38	9.09	15.39	18.26	10.88	12.61	4.98	30.77	13.80	10.18
Canada	49.38	11.26	7.88	15.92	18.28	12.16	14.47	4.93	27.31	13.74	10.98
World	5.34	1.40	0.97	1.37	2.32	1.23	1.89	0.61	3.31	0.97	1.22

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The results for the last six-year period show that Alberta’s output per capita was superior to Canada’s in all 11 specialties (Table IV).

Table IV Average of yearly papers per capita (papers-year/10⁶ inhab.) for selected provinces, Canada, and the world in 11 specialties and for the 2000 to 2005 period

Region	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
AB	74.43	28.36	11.02	21.06	29.27	19.98	20.49	5.63	36.70	27.11	11.43
BC	50.17	11.73	7.68	26.08	21.84	12.31	24.38	4.99	23.54	11.42	9.64
ON	59.31	20.77	9.04	21.24	21.66	11.83	26.89	6.93	24.91	16.52	15.78
QC	65.35	23.45	10.45	18.82	20.02	12.58	17.76	4.80	31.91	14.06	9.34
Canada	53.23	16.73	8.13	18.42	19.43	12.07	18.97	4.93	24.73	14.21	10.91
World	5.41	1.53	0.92	1.55	2.41	1.32	2.28	0.58	2.98	0.87	1.36

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The specialization index (SI) is an indicator of the intensity of research within a specific research area in an entity (i.e., province or country) relative to the intensity of research within the same research area in the world; a score above one means that an entity specializes in the research area relative to the world.

For the whole 24-year period, Alberta was specialized (i.e. $SI > 1.00$) in 7 out of the 11 specialties considered; only Quebec was specialized a greater number of these fields, with 9 out of 11 (Table V). Among the 11 specialty fields analyzed, Alberta was mostly specialized in Physiology (SI of 2.12) and Microbiology (SI of 1.53). Conversely, it was relatively unspecialized in Surgery (SI of 0.64) and Oncology (SI of 0.80). As for Canada, it was specialized in only five fields. It obtained its highest scores in Physiology and Genetics and the lowest scores in Oncology and Immunology.

Table V Specialization Index (SI) by province in 11 specialties, 1982–2005

Region	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
AB	1.27	1.05	0.95	1.27	1.09	1.53	0.80	0.87	1.08	2.12	0.64
BC	0.88	0.62	0.76	1.59	0.85	1.03	0.99	0.78	0.78	1.32	0.76
ON	0.95	0.94	0.90	1.30	0.82	1.02	1.01	0.99	0.79	1.52	1.23
QC	1.30	1.28	1.18	1.39	0.97	1.10	0.82	1.02	1.16	1.77	1.02
Canada	1.05	0.92	0.93	1.32	0.89	1.11	0.87	0.92	0.94	1.61	1.01
World	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Over the four six-year periods, the SI of Alberta grew steadily in two specialties: Cardiovascular System (SI climbing from 0.43 in 1982–1987 to 1.60 in 2000–2005) and Physiology (SI from 1.32 to 2.70). Its most important shifts in research intensity were in Genetics (SI from 1.54 to 1.17) and Microbiology (SI from 1.73 to 1.30) (Table VI).

Table VI Specialization Index (SI) of Alberta in 11 specialties and by six-year period, 1982–2005

	1982-1987	1988-1993	1994-1999	2000-2005
BCM	1.30	1.31	1.31	1.18
CVS	0.43	0.73	1.06	1.60
CLB	0.98	0.86	0.94	1.03
GEN	1.54	1.31	1.19	1.17
IMM	1.02	1.09	1.16	1.05
MCB	1.73	1.67	1.56	1.30
ONC	0.90	0.69	0.85	0.77
PED	0.79	0.88	0.96	0.85
PHM	1.09	1.06	1.13	1.06
PHY	1.32	1.88	2.38	2.70
SUR	0.51	0.66	0.59	0.73

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The average of relative impact factors (ARIF) is an indicator of the expected impact of papers from an entity relative to the expected impact of papers at the world level; a score above one means that an entity publishes in journals that are more cited than the world average for papers in the same fields. For example, in the area of Cardiovascular System, Alberta performed better than the world with an ARIF of 1.38 (Table VII) over the 1982–2005 period. This means that on average, Albertan papers were published in journals that had 38% greater impact than world papers. For the 24-year period, Albertan papers had an expected impact at least 10% above the world level in four specialties: Cardiovascular System (ARIF of 1.38), Pediatrics (ARIF of 1.24), Oncology (ARIF of 1.14), and Cell Biology (ARIF of 1.12). This performance was better than that of Canada (three specialties) but inferior to that of Quebec, Ontario, and BC (five specialties). Compared to Canada and leading provinces, the impact of papers from Albertan researchers was particularly high in Cardiovascular System and Cell Biology. However, it was lagging behind the world in Surgery and was generally behind its Canadian counterparts, mostly in Genetics (Table VII).

Table VII Average of relative impact factors (ARIF) by province in 11 specialties, 1982–2005

Region	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
AB	0.99	1.38	1.12	0.96	1.00	1.05	1.14	1.24	1.07	1.03	0.85
BC	0.99	1.11	0.96	1.06	1.16	1.20	1.23	1.30	1.06	0.89	0.89
ON	1.01	1.25	1.02	1.13	1.12	1.00	1.21	1.34	1.02	0.96	0.90
QC	1.00	1.28	1.10	1.19	1.06	1.03	1.25	1.29	1.14	0.98	0.91
Canada	0.98	1.24	1.02	1.07	1.06	1.04	1.19	1.29	1.06	0.97	0.88
World	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Over the last four six-year periods, the highest increases in ARIF for Alberta were seen in Cell Biology and Oncology. The largest decline for Alberta was observed in Cardiovascular System, which after rising steadily in the first three periods, dropped sharply between the last two periods (Table VIII). Canada also saw a general increase of its ARIF in both Cell Biology and Oncology, but also in Biochemistry, Immunology, and Surgery. A general decline in ARIFs was seen in Cardiovascular System and Pediatrics at the Canadian level (data not shown).

Table VIII Average of relative impact factors (ARIF) of Alberta in 11 specialties and by six-year period, 1982–2005

	1982-1987	1988-1993	1994-1999	2000-2005
BCM	0.99	0.95	0.97	1.03
CVS	1.40	1.45	1.50	1.28
CLB	0.98	0.98	1.28	1.20
GEN	0.99	0.85	1.04	0.96
IMM	1.09	1.01	0.91	1.04
MCB	1.04	1.09	1.07	1.00
ONC	1.09	1.11	1.15	1.16
PED	1.24	1.18	1.24	1.29
PHM	1.07	1.05	1.10	1.06
PHY	0.94	1.10	1.03	0.99
SUR	0.84	0.76	0.83	0.91

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The scientometric positioning of Alberta, leading Canadian provinces, and Canada in each specialty field are also presented in Appendix C in a series of two-dimensional graphs based on SI and ARIF for the last two periods (1994–1999 and 2000–2005). The size of bubbles is proportional to the absolute scientific output. The SI and the ARIFs are log transformed so that the origin (0, 0) represents the world average. For both indicators, a value above zero means that the score is higher than the world level. Thus, leaders are in the top right quadrant (high level of specialization and impact), while provinces that are lagging are in the lower left quadrant.

During the 1994 to 1999 period, Alberta's main strengths were in Cardiovascular System, Genetics, Microbiology, Physiology, and Pharmacology & Pharmacy, with both specialization and impact above the world level in these specialties. Its main weakness in that period was in Surgery, as exhibited by its location in the lower left quadrant. Alberta was also weak in Biochemistry and Immunology, with slight specialization and low impact. From the 1994–1999 period to the 2000–2005 period, Alberta's position has improved with respect to both indicators only in Surgery. By comparison, BC, Ontario, and Canada progressed in six fields and Quebec in three.

With a decrease in both indicators in three specialties and a decrease in impact in four specialties, Alberta had the worst performance. Especially preoccupying for Alberta are the reductions in impact and specialization in Genetics and Pharmacology & Pharmacy where most other provinces gained ground in at least one indicator. Similarly, while all other entities were improving their positioning

relative to both indicators, Alberta was losing ground with respect to impact in Physiology and with respect to specialization in Biochemistry and Oncology. Consequently, Alberta's main strengths in the latest six-year period evolved to Biochemistry, Cardiovascular System, Cell Biology, Immunology, Microbiology, and Pharmacology & Pharmacy.

When considering the multicriteria ranking of leading provinces, Alberta emerged as an established leader in five specialties where it ranked first overall for the entire 1982–2005 period (Table IX). This performance was significantly better than the three other leading provinces, Ontario ranking first overall in three specialties, Quebec in two, and BC in one.

Table IX Multicriteria ranking of selected provinces comprising number of papers, papers per capita, SI, and ARIF, in 11 specialties, 1982–2005

Rank	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
1	QC	AB (1)	AB	BC	AB (1)	AB	ON	ON	QC	AB	ON
2	ON	QC (1)	QC	ON (2)	ON (1)	BC (2)	BC	QC	AB	ON (2)	QC
3	AB	ON	ON	QC (2)	QC	ON (2)	QC	AB	ON	QC (2)	BC
4	BC	BC	BC	AB	BC	QC (2)	AB	BC	BC	BC	AB

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Alberta's top specialties in multicriteria ranking have changed considerably over the four six-year periods (Table X). In the 2000–2005 period, as in the 1982–1987 period, the province ranked first or second in six specialties. However, while Immunology, Microbiology and Pharmacology & Pharmacy were among Alberta's leading specialties in both periods, Biochemistry, Genetics, and Oncology were replaced as top ranked specialties by Cardiovascular System, Cell Biology, and Physiology in the 2000–2005 period. Alberta was also in excellent position in Pharmacology & Pharmacy, where it consistently ranked second. Despite a second position in the 1994–1999 period, Alberta has ranked first in Immunology in all other periods. Finally, after occupying the leading position in the first three periods, Alberta fell to the second position in Microbiology in 2000–2005.

In Cardiovascular System and Physiology, Alberta has ranked first for the last three periods after being ranked third in the 1982–1987 period. In Cell Biology, it went from being ranked third in the first period to the top position in the 2000–2005 period.

The position of Alberta was less advantageous among the other specialties. Indeed, Alberta went from first to third position in Biochemistry between 1982–1993 and 1994–2005. In Genetics, Alberta went from the first position in the early 1980s to being ranked fourth for the last three periods and overall (1982–2005). A similar decline in ranking was observed in Oncology, while in Pediatrics and Surgery, Alberta has repeatedly ranked third or fourth. It is important to note that Alberta's ranking has thus decreased in some of the most active fields of research in terms of absolute number of papers at the Canadian and world levels (e.g., Biochemistry) while it gained in fields with lower outputs (e.g., Cell Biology).

While Quebec's rankings remained mostly stable across the 11 specialties from the 1982–1987 period to the 2000–2005 period, BC improved and Ontario lost some ground. BC, which was third or fourth in all specialties in the 1982–1987 period, was in that same situation in seven specialties in the last period. Conversely, Ontario, which ranked third or fourth in only two specialties for the 1982–1987 period, had 6 out of 11 specialties in the bottom two positions in the 2000–2005 period (Table X).

Table X Multicriteria ranking of selected provinces comprising number of papers, papers per capita, SI, and ARIF, in 11 specialties and by six-year period, 1982–2005

Rank	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
1982-1987											
1	AB	ON (1)	ON (1)	AB (1)	AB	AB	ON	ON	QC	QC	ON
2	QC	QC (1)	QC (1)	ON (1)	ON	ON	AB	QC	AB	ON	QC
3	ON	AB	AB	BC	QC	BC (3)	BC	AB	ON	AB	BC
4	BC	BC	BC	QC	BC	QC (3)	QC	BC	BC	BC	AB
1988-1993											
1	AB	AB (1)	QC	ON (1)	AB	AB	ON	ON	QC	AB	ON
2	ON (2)	ON (1)	AB (2)	QC (1)	QC	ON	BC	QC	AB	ON	QC
3	QC (2)	QC (1)	ON (2)	BC	ON	QC	QC	BC	ON	QC	BC
4	BC	BC	BC	AB	BC	BC	AB	AB	BC	BC	AB
1994-1999											
1	ON (1)	AB	QC	ON	ON	AB	ON	ON	QC	AB	ON
2	QC (1)	QC	AB	BC (2)	AB	BC	BC	QC	AB	ON (2)	QC
3	AB	ON	ON	QC (2)	QC	ON	QC	AB	ON	QC (2)	BC
4	BC	BC	BC	AB	BC	QC	AB	BC	BC	BC	AB
2000-2005											
1	QC	AB (1)	AB	BC (1)	AB (1)	QC	ON	ON	QC	AB	ON
2	ON	QC (1)	QC	ON (1)	BC (1)	AB	BC	BC	AB	QC	QC
3	AB	ON	ON	QC	ON	BC	QC	QC	ON	ON	AB (3)
4	BC	BC	BC	AB	QC	ON	AB	AB	BC	BC	BC (3)

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

3 Benchmarking of top institutions' in Alberta

In order to benchmark Alberta's institutions in each specialty field, three indicators quantified over a 24-year period (1982–2005) were used: 1) number of papers; 2) specialization index (SI); 3) average of relative impact factors (ARIF). Table XI presents the performance of the Universities of Alberta and Calgary in all 11 specialties between 1982 and 2005 in terms of output and impact. The University of Alberta was the most productive in terms of absolute number of papers published between 1982 and 2005 in 9 of 11 specialty fields. While the University of Calgary surpassed the University of Alberta by only a few papers in Pediatrics, it conclusively ranked first in Physiology. With almost double the number of publications of the University of Calgary, the University of Alberta was dominant in four specialties: Biochemistry, Immunology, Oncology, and Pharmacology & Pharmacy. The only field in which the University of Alberta and the University of Calgary were not top ranking was in Oncology, where the Edmonton-based Cross Cancer Institute (with 353 papers) ranked second behind the University of Alberta (Table XII). The university sector obtained its best results in Physiology, with an SI of 4.06 for the University of Calgary. This university was also specialized in Biochemistry, Cardiovascular System, Cell Biology, Genetics, Immunology, Microbiology, Pediatrics, and Pharmacology & Pharmacy. Still, the University of Alberta surpassed Calgary in specialization in three of these fields: Biochemistry, Immunology, and Pharmacology & Pharmacy (Table XI).

Table XI Comparison of the output of the Universities of Alberta and Calgary based on the number of papers, SI, and ARIF (1982–2005)

Specialty	U. of Alberta			U. of Calgary		
	Papers	SI	ARIF	Papers	SI	ARIF
Biochemistry	3132	1.52	1.00	1705	1.40	0.98
Cardiovascular System	535	0.98	1.36	493	1.54	1.40
Cell Biology	386	1.04	1.15	275	1.26	1.12
Genetics	701	1.31	0.93	462	1.46	1.06
Immunology	1,113	1.23	1.00	629	1.18	1.10
Microbiology	658	1.38	1.11	524	1.87	1.09
Oncology	508	0.69	1.19	273	0.62	1.00
Pediatrics	172	0.74	1.36	180	1.31	1.14
Pharmacology & Pharmacy	1,542	1.22	1.04	786	1.05	1.21
Physiology	618	1.65	1.03	894	4.06	1.03
Surgery	241	0.51	0.88	207	0.74	0.84

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The University of Calgary leads in impact with an ARIF of 1.40 in Cardiovascular System. The University of Alberta was close behind, with a 1.36 in both Cardiovascular System and Pediatrics. Both universities also had great scientific impacts in Oncology and Pharmacology & Pharmacy (Table XI). Two other institutions with more than 150 publications in a single field matched these results, namely the Cross Cancer Institute and the Tom Baker Center in Oncology (Table XII).

Over the entire 24-year period, researchers from the Cross Cancer Institute have also authored more than 30 papers in Biochemistry (92 papers) and in Immunology (34 papers). Among the other leading Albertan institutions, not surprisingly, medical centers appeared most commonly, such as the Alberta Children's Hospital, the Tom Baker Cancer Centre, the University of Alberta Hospital, and the Foothills Medical Centre (Table XII). The specialization of the two main Albertan universities was at its lowest in Oncology and Surgery for the University of Calgary and in Surgery, Oncology, and Pediatrics for the University of Alberta. However, the low SIs obtained by both universities in these specialties could be explained, at least in part, by the strong specialization of affiliated centers in these same specialties (e.g., the Cross Cancer Institute and the University of Alberta in Oncology).

Table XII Comparison of the output of leading Albertan health centres and hospitals based on the number of papers, SI, and ARIF (1982–2005)

Specialty	Alberta Children's Hospital			Cross Cancer Institute			Foothills Medical Centre			Tom Baker Cancer Centre			University of Alberta Hospital		
	Papers*	SI	ARIF	Papers*	SI	ARIF	Papers*	SI	ARIF	Papers*	SI	ARIF	Papers*	SI	ARIF
BCM				92	1.67	1.03									
CVS							109	8.21	1.47				46	3.89	1.16
CLB															
GEN	154	17.70	0.98										31	2.67	1.05
IMM				34	1.41	0.93	50	2.27	0.60				63	3.22	0.81
MCB													34	3.29	0.89
ONC	45	3.73	0.75	353	17.81	1.24	35	1.94	0.83	152	23.23	1.21			
PED	66	17.40	1.12												
PHM							48	1.55	1.09				41	1.49	1.08
PHY															
SUR	30	3.89	0.65				40	3.46	0.76				42	4.08	0.79

* Only data for specialties where institutions have obtained at least 30 papers are presented

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Provincial and Federal government institutions with facilities in Alberta also played leading roles in some specialties, including Alberta Health and Wellness in Immunology (43 papers), Microbiology (43 papers), and Oncology (48 papers); Agriculture & Agri-Food Canada in Microbiology (149 papers) and Genetics (69 papers); and National Defence Canada in Pharmacology & Pharmacy (104 papers) (Table XIII). As for the University of Lethbridge, it was among the leading institutions only in Biochemistry, with 41 papers between 1982 and 2005 (data not shown). Only one private company was found among the most productive Albertan institutions, namely Biomira in Oncology, with 34 papers in the 24-year period (data not shown). Institutions with high ARIFs, albeit with a relatively low output, include the Royal Alexandra Hospital in Pediatrics (ARIF of 1.64 with 47 papers, data not shown), the Foothills Medical Centre in Cardiovascular System (ARIF of 1.47 with 109 papers, Table XII), and Biomira in Oncology (ARIF of 1.35 with 35 papers, data not shown). Overall, the weakest performance of Albertan institutions in terms of scientific impact was in Surgery, where all institutions with 30 papers or more obtained ARIFs between 0.65 and 0.88 (Table XI and Table XII).

Table XIII Comparison of the output of leading provincial and federal government institutions from Alberta based on the number of papers, SI, and ARIF (1982–2005)

Specialty	Agriculture & Agri-Food Canada			Alberta Health and Wellness			National Defence Canada		
	Papers*	SI	ARIF	Papers*	SI	ARIF	Papers*	SI	ARIF
BCM									
CVS									
CLB									
GEN	69	1.46	0.47						
IMM				43	3.17	0.76			
MCB	149	3.54	0.71	43	6.00	1.04			
ONC				48	4.30	1.02			
PED									
PHM							104	7.29	0.88
PHY									
SUR									

* Only data for specialties where institutions have obtained at least 30 papers are presented

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

When both the SI and ARIF indicators are considered, the top performance by an Albertan university was obtained in Cardiovascular System by the University of Calgary (SI of 1.54 and ARIF of 1.40, Table XI). The results of other institutions were also noteworthy, primarily those of the Royal Alexandra Hospital in Pediatrics (ARIF of 1.64, data not shown), the Foothills Medical Centre in Cardiovascular System (SI of 8.21 and ARIF of 1.47, Table XII), and the Cross Cancer Institute (ARIF of 1.24, Table XII), the Tom Baker Cancer Centre (ARIF of 1.21, Table XII), and Biomira (ARIF of 1.35, data not shown) in Oncology. Conversely, the outputs of all institutions involved in the field of Surgery were characterized by low specialization and impact (Table XI and Table XII). A similar situation was observed for the University of Lethbridge in Biochemistry (SI of 0.58 and ARIF of 0.69, data not shown).

Despite being highly specialized in a research field, institutions like the University of Alberta published papers in Genetics with a relatively weak average impact (SI of 1.31 and ARIF of 0.93, Table XI). Likewise, institutions with low outputs had similar results in some fields, including Agriculture & Agri-Food Canada in both Microbiology (SI of 3.54 and ARIF of 0.71) and Genetics (SI of 1.46 and ARIF of 0.47, Table XIII), National Defence Canada in Pharmacology & Pharmacy (SI of 7.29 and ARIF of 0.88, Table XIII), and the University of Alberta Hospital in both Immunology (SI of 3.22 and ARIF of 0.81) and Microbiology (SI of 3.29 and ARIF of 0.89, Table XII).

The reverse was also true, with some institutions achieving high impact despite relatively weak SI. Above all, the most noteworthy examples came from the University of Alberta in Pediatrics (SI of 0.74 and ARIF of 1.36) and Oncology (SI of 0.69 and ARIF of 1.19, Table XI).

4 Researchers

This section provides an overview of the most active researchers in Alberta between 2000 and 2005 across the 11 specialty fields. Overall, forty researchers have authored 20 publications or more in a single specialty between 2000 and 2005 (Table XIV). In this group, 24 researchers were from the University of Alberta and 16 from the University of Calgary. Almost half of these authors (19) published their papers in the field of Biochemistry. Other specialties represented by researchers having published more than 20 papers in the most recent six-year period included Cardiovascular System (9), Pharmacology & Pharmacy (5), Immunology (4), Genetics (1), Microbiology (1), and Oncology (1).

Paul W. Armstrong was the leader in number of papers published between 2000 and 2005 in a single specialty with 106 papers in the field of Cardiovascular System. He is Professor of Medicine in the Division of Cardiology at the University of Alberta and Senior Attending Cardiologist at the University of Alberta Hospital. Paul W. Armstrong published almost twice as many papers as the closest Albertan contender, Brian D. Sykes. Brian D. Sykes published 55 papers in the field of Biochemistry between 2000 and 2005. He is Professor of Biochemistry at the University of Alberta. Dennis E. Vance rounded out the top three of most active Albertan researchers with 44 papers in Biochemistry. He is also Professor of Biochemistry at the University of Alberta.

Listings of the top author in each specialty are presented in Table XV. Only the top authors in Cell Biology, Pediatrics, Physiology and Surgery have produced less than 20 papers over the most recent six-year period. Eight authors have published 10 papers or more in two specialties during the 2000–2005 period (some data is not shown). Morley D. Hollenberg, a Professor at the Department of Pharmacology and Therapeutics and the Department of Medicine of the University of Calgary, has been the most productive in this group, with 45 papers. In addition to his 35 papers in Pharmacology & Pharmacy (Table XIV), he published 10 papers in Physiology. Also part of this group, and appearing in Table XIV, are Carol E. Cass of the University of Alberta (26 papers in Biochemistry, 11 in Pharmacology & Pharmacy), John L. Wallace of the University of Calgary (25 papers in Pharmacology & Pharmacy, 14 in Physiology), Marek Michalak of the University of Alberta (23 papers in Biochemistry, 10 in Cell Biology), and Paul Kubes of the University of Calgary (20 papers in Immunology, 10 in Physiology). The other Albertan researchers with 10 or more papers in two specialties were Theresa M. Allen (17 papers in Pharmacology & Pharmacy, 15 in Oncology) and Sandra T. Davidge (14 papers in Physiology, 12 in Cardiovascular System) of the University of Alberta, and Pamela A. Sokol of the University of Calgary (11 papers in Microbiology, 10 in Immunology).

Table XIV Albertan researchers with the most papers in one of the 11 specialties, 2000–2005

Researcher	Specialty	Affiliation	Papers	Rk
Paul W. Armstrong	CVS	Dept. of Medicine (Cardiology), Univ. of Alberta	106	1
Brian D. Sykes	BCM	Dept. of Biochemistry, Univ. of Alberta	55	2
Dennis E. Vance	BCM	Dept. of Biochemistry, Univ. of Alberta	44	3
Hans J. Vogel	BCM	Dept. of Biological Sciences, Univ. of Calgary	39	4
Robert S. Hodges	BCM	Dept. of Biochemistry, Univ. of Alberta	37	5
Morley D. Hollenberg	PHM	Dept.s of Pharmacology and Therapeutics and of Medicine, Univ. of Calgary	35	6
Jonathan R.T. Lakey	IMM	Dept. of Surgery, Univ. of Alberta	32	7
Ronald N. McElhanev	BCM	Dept. of Biochemistry, Univ. of Alberta	29	8
Andrew M. James Shapiro	IMM	Dept. of Surgery (General Surgery), Univ. of Alberta	29	8
Edward E. Knaus	PHM	Fac. of Pharmacy and Pharmaceutical Sciences, Univ. of Alberta	29	8
William A. Ghali	CVS	Dept.s of Med. (General Internal Med.) & of Community Health Sciences, Univ. of Calgary	28	11
Robert S. Sheldon	CVS	Dept. of Cardiac Sciences, Univ. of Calgary	27	12
Todd J. Anderson	CVS	Dept. of Cardiac Sciences, Univ. of Calgary	27	12
John R. Mackey	ONC	Dept. of Oncology, Univ. of Alberta	27	12
Carol E. Cass	BCM	Dept. of Oncology, Univ. of Alberta	26	15
Michael N.G. James	BCM	Dept. of Biochemistry, Univ. of Alberta	26	15
Susan P. Lees-Miller	BCM	Dept. of Biochemistry and Molecular Biology, Univ. of Calgary	26	15
James D. Young	BCM	Dept. of Physiology, Univ. of Alberta	25	18
John L. Wallace	PHM	Dept. of Pharmacology and Therapeutics, Univ. of Calgary	25	18
Chris R. Triggle	PHM	Dept. of Pharmacology & Therapeutics, Univ. of Calgary	25	18
David S. Wishart	BCM	Dept.s of Biological Sciences and of Computing Science, Univ. of Alberta	24	21
Gerald W. Zamponi	BCM	Dept. of Physiology and Biophysics, Univ. of Calgary	24	21
Luis B. Agellon	BCM	Dept. of Biochemistry, Univ. of Alberta	24	21
L. Brent Mitchell	CVS	Dept. of Cardiac Sciences, Univ. of Calgary	24	21
Marek Michalak	BCM	Dept. of Biochemistry, Univ. of Alberta	23	25
Ruthven N.A.H. Lewis	BCM	Dept. of Biochemistry, Univ. of Alberta	23	25
Jean E. Vance	BCM	Dept. of Medicine (Endocrinology and Metabolism), Univ. of Alberta	22	27
Larry Fliegel	BCM	Dept. of Biochemistry, Univ. of Alberta	22	27
Finlay A. McAlister	CVS	Dept. of Medicine (General Internal Medicine), Univ. of Alberta	22	27
Pere Santamaria	IMM	Dept. of Microbiology and Infectious Diseases, Univ. of Calgary	22	27
Glen B. Baker	PHM	Dept. of Psychiatry, Univ. of Alberta	22	27
Cyril M. Kay	BCM	Dept. of Biochemistry, Univ. of Alberta	21	32
Joel H. Weiner	BCM	Dept. of Biochemistry, Univ. of Alberta	21	32
Monica M. Palcic	BCM	Dept. of Chemistry, Univ. of Alberta	21	32
Anne M. Gillis	CVS	Dept. of Cardiac Sciences, Univ. of Calgary	21	32
D. George Wyse	CVS	Dept. of Cardiac Sciences, Univ. of Calgary	21	32
Renee H. Martin	GEN	Dept. of Medical Genetics, Univ. of Calgary	21	32
Merril L. Knudtson	CVS	Dept. of Cardiac Sciences, Univ. of Calgary	20	38
Paul Kubes	IMM	Dept. of Physiology and Biophysics, Univ. of Calgary	20	38
Diane E. Taylor	MCB	Dept. of Medical Microbiology and Immunology, Univ. of Alberta	20	38

BCM: Biochemistry, CVS: Cardiovascular System, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PHM: Pharmacology & Pharmacy
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Table XV Top ranking author in each specialty, 2000-2005

Specialty	Researcher	Affiliation	Papers
BCM	Brian D. Sykes	Department of Biochemistry, University of Alberta	55
CVS	Paul W. Armstrong	Department of Medicine (Cardiology), University of Alberta	106
CLB	Richard A. Rachubinski	Department of Cell Biology, University of Alberta	18
GEN	Renee H. Martin	Department of Medical Genetics, University of Calgary	21
IMM	Jonathan R.T. Lakey	Department of Surgery, University of Alberta	32
MCB	Diane E. Taylor	Department of Medical Microbiology and Immunology, Univ. of Alberta	20
ONC	John R. Mackey	Department of Oncology, University of Alberta	27
PED	Alexander K.C. Leung	Department of Pediatrics, University of Calgary	7
PHM	Morley D. Hollenberg	Dep. of Pharmacology and Therapeutics and of Medicine, Univ. of Calgary	35
PHY	Keith A. Sharkey	Department of Physiology & Biophysics, University of Calgary	18
SUR	David L. Sigalet	Department of Surgery, University of Calgary	16

BCM: Biochemistry, CVS: Cardiovascular System, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PHM: Pharmacology & Pharmacy

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

5 Scientific collaborations

This section provides an overview of Alberta's scientific collaborations at the inter-institutional, inter-provincial, and international levels over the 1994–2005 period in all 11 specialties. Table XVI lists the number and rate of collaborations between Albertan institutions in each specialty through the 1994 to 2005 period. The Universities of Alberta and Calgary had the highest number of inter-institutional collaborations within Alberta in most specialty fields. However, their rate of collaboration was generally well below that of other Albertan institutions. The Universities of Alberta and Calgary rarely had more than 30% of their papers published in collaboration with another institution from Alberta (Table XVI). Both universities highest collaboration rates were in Oncology and Pediatrics. Conversely, these Albertan universities collaborated in less than 10% of their papers with other institutions within Alberta in the fields of Biochemistry, Cell Biology, and Physiology. The widest difference in collaboration between the two universities was observed in Genetics, with the University of Alberta only collaborating in 11% of its papers compared to 30% for the University of Calgary. This is likely the result of a strong association between the Alberta Children's Hospital and the University of Calgary in that field.

Table XVI Collaborations of top Albertan institutions within Alberta in 11 specialties, rate and absolute number, 1994–2005

Institutions	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
Univ. of Alberta	5.6% 103	15.0% 64	5.6% 13	11.1% 49	13.2% 86	12.6% 43	36.3% 113	36.7% 40	11.2% 92	7.1% 26	24.5% 36
Univ. of Calgary	4.9% 46	24.3% 89	9.8% 14	30.3% 74	19.6% 77	18.5% 51	47.8% 89	43.3% 39	10.4% 44	3.5% 21	25.2% 37
Cross Cancer Institute	67.2% 41			41.2% 7	94.4% 17		48.0% 95		83.3% 10		76.9% 10
Univ. of Alberta Hosp.		37.8% 14		40.0% 6	48.1% 25	35.5% 11	66.7% 4	66.7% 10	54.2% 13		46.2% 12
Foothills Medical Centre		68.4% 39			83.3% 25		78.9% 15	100.0% 8	52.2% 12		33.3% 8
Alberta Health & Wellness		100.0% 10			48.7% 19	50.0% 14	64.0% 16	75.0% 6	80.0% 8	100.0% 4	68.8% 11
Tom Baker Cancer Centre					88.9% 16		63.4% 71				77.8% 7
Alberta Children's Hosp.	60.0% 6			76.6% 49	92.9% 13		57.8% 26	76.9% 30			44.4% 8

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The intra-provincial collaboration rates of non-academic institutions were typically higher than those of both universities (Table XVI). For instance, a good number of non-academic institutions had more than two-thirds of their papers co-authored with another Albertan institution. Among those with relatively high absolute numbers of collaborations (30 or more) were the Foothills Medical Centre in Cardiovascular System (68%), the Alberta Children's Hospital in Genetics (77%) and Pediatrics (77%), and the Cross Cancer Institute in Biochemistry (68%).

Table XVII lists the number and rate of inter-provincial collaborations of Albertan institutions in the 1994–2005 period. In 9 out of 11 specialties, the Albertan institution with the highest number of collaborations with other Canadian provinces was the University of Alberta. It was only outdone by the Cross Cancer Institute and the Tom Baker Cancer Centre in Oncology and by the University of Calgary in Surgery. In all specialty fields except Oncology, Pediatrics, and Surgery, the inter-provincial collaboration rates of the University of Alberta were above their intra-provincial counterparts. Both universities had their highest collaboration rate in Cardiovascular System and their lowest rates in Cell Biology (Alberta) and Physiology (Calgary). Among the non-academic institutions with more than 20 inter-provincial collaborations, only the Foothills Medical Center in Cardiovascular System had a collaboration rate above the 50% mark.

Table XVII Collaborations of top Albertan institutions with other Canadian provinces in 11 specialties, rate and absolute number, 1994–2005

Institutions	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
Univ. of Alberta	17.6% 321	30.8% 132	12.9% 30	20.9% 92	14.7% 96	13.2% 45	14.1% 44	27.5% 30	18.0% 148	16.8% 62	21.8% 32
Univ. of Calgary	12.5% 117	34.4% 126	10.5% 15	23.0% 56	21.9% 86	14.5% 40	22.0% 41	26.7% 24	13.0% 55	9.4% 57	23.1% 34
Cross Cancer Institute	13.1% 8			29.4% 5	16.7% 3		29.8% 59				
Univ. of Alberta Hosp.	25.0% 1	51.4% 19		20.0% 3	34.6% 18	29.0% 9		40.0% 6	33.3% 8		23.1% 6
Foothills Medical Centre		54.4% 31			16.7% 5		5.3% 1	75.0% 6	39.1% 9		41.7% 10
Alberta Health & Wellness					53.8% 21	42.9% 12	32.0% 8		50.0% 5		25.0% 4
Tom Baker Cancer Centre							43.8% 49				
Agriculture & Agri-Food Canada	20.0% 3			44.2% 19		29.9% 26					
Alberta Children's Hosp.	10.0% 1			31.3% 20			11.1% 5	35.9% 14			22.2% 4
National Defence Canada					36.8% 7	50.0% 7			14.6% 7		

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The prevailing inter-institutional collaborations within Alberta and Canada in the different specialties are depicted in Appendix D. In these figures, each institution is represented by a circle (node) with a size proportional to its total number of papers in collaboration with Albertan institutions during the 1994–2005 period. Only nodes with at least 12 collaborations with Albertan institutions over the 12-year period are displayed. Links between nodes identify pairs of institutions with more than six collaborations together in the period. Links' widths are proportional to the number of collaborations.

The figures clearly show that the top research areas of Alberta in terms of absolute number of papers were not necessarily those with the most extensive collaboration network. For instance, the scientific output of Alberta in Pharmacology & Pharmacy and Physiology were among the highest while their collaboration networks were limited. On the other hand, the network of collaborators in Pediatrics

was substantial, even though it represented the specialty where Alberta had the fewest number of papers over the period. However, the network of collaborators in one of Alberta's least active specialty, Cell Biology, was not presented, owing to the particularly small number of inter-institutional collaborations in that field.

The University of Alberta and the University of Calgary had important national collaboration networks in Biochemistry, Cardiovascular System, Immunology, Oncology, and Pediatrics. As for non-academic Albertan institutions, their collaboration networks were mostly regional, with the exception of the Foothills Medical Centre in Cardiovascular System, the Tom Baker Cancer Centre, and the Cross Cancer Institute in Oncology, and the Alberta Children's Hospital in Pediatrics. In general, the links between Albertan institutions were not stronger than their links with institutions from the rest of Canada.

Within Alberta, the University of Calgary was the most important collaborator with the University of Alberta in 9 out of the 11 specialty fields. The other major collaborator with the University of Alberta was the Cross Cancer Institute in Biochemistry and Oncology. Conversely, the University of Alberta was the most important collaborator with the University of Calgary. However, this university had many other frequent collaborators in the different specialty fields, including the Alberta Children's Hospital in Genetics, Oncology, and Pediatrics, the Calgary Medical Laboratories in Microbiology, the Tom Baker Cancer Centre in Oncology, and the Foothills Medical Centre in Cardiovascular System and Immunology.

At the national level, Albertan institutions collaborated mostly with the University of Toronto which was among the top 3 Canadian collaborators in all specialty fields except Microbiology. The other most frequent Canadian collaborators of Albertan institutions across the 11 specialty fields were the University of British Columbia, McGill University, the University of Western Ontario, the University of Manitoba, the University of Saskatchewan, the Hospital for Sick Children, and Dalhousie University.

Table XVIII Number of papers from Alberta authored in collaboration with researchers from other Canadian provinces in 11 specialties, 1994–2005

Specialty	ON	BC	QC	Total
Biochemistry	236	97	80	450
Cardiovascular System	193	72	102	270
Cell Biology	26	4	17	49
Genetics	80	41	33	171
Immunology	129	67	57	222
Microbiology	70	28	27	137
Oncology	124	55	52	168
Pediatrics	50	27	23	63
Pharmacology & Pharmacy	104	66	54	241
Physiology	50	24	34	122
Surgery	38	26	19	83

AB: Alberta, BC: British Columbia, ON: Ontario, QC: Quebec, Total: all Canadian provinces except Alberta
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Overall, Albertan institutions collaborated mainly with institutions from Ontario and BC (Table XVIII). In all 11 specialties, Ontario ranked first in terms of number of papers authored in collaboration with other Albertan institutions. In most specialty fields, Ontario collaborated on more than twice the number of papers of its closest follower. The highest number of collaborations between Albertan institutions and Ontario was 236 in Biochemistry. BC ranked second in eight specialties; it was surpassed by Quebec only in Cardiovascular System, Cell Biology, and Physiology.

The top three specialties for the number of papers authored by Albertan institutions in collaboration with other Canadian Provinces were: Biochemistry (450), Cardiovascular System (270), and Pharmacology & Pharmacy (241) (Table XVIII). Overall, international collaborations were more frequent for Albertan institutions than inter-provincial collaborations in all specialties except Surgery (82 with the world, compared to 83 with the rest of Canada).

In absolute numbers, the top three specialties for international collaborations with Albertan institutions were: Biochemistry (1,162), Pharmacology & Pharmacy (480), and Immunology (426) (Table XIX). However, the highest collaboration rates with foreign countries were obtained in Oncology (49.6%), Cardiovascular System (45.8%), and Genetics (45%).

Table XIX Collaborations of Alberta with top foreign countries in 11 specialties, rate and absolute number, 1994–2005

Specialty	US	UK	GE	JP	FR	AU	NL	BE	World
Biochemistry	24.0% 675	4.9% 137	3.1% 88	3.6% 100	2.5% 71	1.1% 30	1.7% 48	0.5% 13	41.3% 1,162
Cardiovascular System	37.6% 311	5.9% 49	4.7% 39	1.6% 13	3.5% 29	3.9% 32	6.0% 50	7.3% 60	45.8% 379
Cell Biology	27.9% 104	2.7% 10	6.7% 25	3.5% 13	2.4% 9	1.3% 5		1.3% 5	44.0% 164
Genetics	30.9% 233	9.5% 72	4.9% 37	3.2% 24	2.1% 16	3.6% 27	2.3% 17	1.1% 8	45.0% 340
Immunology	23.7% 265	3.9% 44	1.8% 20	2.4% 27	1.7% 19	2.1% 24	1.4% 16		38.1% 426
Microbiology	19.4% 145	2.3% 17	2.1% 16	2.0% 15	1.6% 12	2.7% 20	0.8% 6		32.0% 239
Oncology	32.6% 235	5.1% 37	6.3% 45	2.8% 20	3.1% 22	2.2% 16	2.6% 19	1.8% 13	49.6% 357
Pediatrics	20.4% 44	4.2% 9	4.2% 9	1.9% 4		3.7% 8	2.3% 5		34.7% 75
Pharmacology & Pharmacy	18.0% 248	5.5% 76	1.9% 26	3.5% 48	2.5% 35	1.1% 15	0.7% 9	2.0% 28	34.9% 480
Physiology	19.1% 184	4.7% 45	1.8% 17	2.7% 26	1.7% 16	2.2% 21	0.6% 6		35.1% 338
Surgery	17.2% 62	1.4% 5	1.1% 4	1.4% 5	1.1% 4	2.5% 9	1.1% 4		22.8% 82

US: United States, UK: United Kingdom, GE: Germany, JP: Japan, AU: Australia, FR: France, NL: Netherlands, BE: Belgium, World: all Albertan collaborations with foreign countries
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Among the leaders in international collaboration with Alberta, four countries stood out. The US was the top foreign collaborator in all 11 specialties. With 675 collaborations, Biochemistry was by far the leading specialty with the US. However, the highest collaboration rates were in Cardiovascular System (37.6%), Oncology (32.6%), and Genetics (30.9%). The other three foreign countries with

which researchers have collaborated the most were, in terms of absolute number of collaborations: the UK, which ranked second behind the US in 5 specialties; Germany runner-up in 4 specialties; and Japan (Table XIX). Alberta's international collaboration rate only rarely exceeded 5%.

The University of Alberta and the University of Calgary were by far the most important Albertan institutions involved in foreign collaborations (Table XX). The University of Alberta led in number of papers coauthored with foreign countries in 8 out of 11 specialties. Both Universities had collaboration rates above 25% in all specialties except surgery (18%). The universities of Alberta and Calgary had their highest international collaboration rates in Cardiovascular System (50%) and Oncology (49%), respectively. The only other Albertan institution with a sizeable number of foreign collaborations in a specialty field was the Cross Cancer Institute in Oncology, with 100.

Table XX Collaborations of top Albertan institutions with foreign countries, rate and absolute number, 1994–2005

Institutions	BCM	CVS	CLB	GEN	IMM	MCB	ONC	PED	PHM	PHY	SUR
Univ. of Alberta	39.0% 711	49.8% 213	45.3% 105	43.0% 189	35.1% 229	36.5% 125	44.1% 137	25.7% 28	32.9% 271	33.2% 122	18.4% 27
Univ. of Calgary	43.6% 408	33.3% 122	40.6% 58	44.3% 108	41.6% 163	26.8% 74	48.9% 91	37.8% 34	36.5% 154	36.1% 219	18.4% 27
Cross Cancer Institute	55.7% 34			52.9% 9	22.2% 4		50.5% 100		66.7% 8		30.8% 4
Alberta Children's Hosp.	80.0% 8			64.1% 41			71.1% 32	48.7% 19			22.2% 4
Univ. of Alberta Hosp.	100.0% 4	40.5% 15		33.3% 5	26.9% 14	35.5% 11		6.7% 1	20.8% 5		15.4% 4
Foothills Medical Centre		45.6% 26			13.3% 4		31.6% 6	62.5% 5	26.1% 6		41.7% 10
Tom Baker Cancer Centre							39.3% 44				44.4% 4
Agriculture & Agri-Food Canada	33.3% 5			44.2% 19		17.2% 15					
Alberta Health & Wellness					38.5% 15	32.1% 9	20.0% 5		20.0% 2		18.8% 3
Biomira	47.1% 8				41.7% 5		48.0% 12				
National Defence Canada					52.6% 10	42.9% 6			18.8% 9		
Univ. of Lethbridge	31.0% 9			53.3% 8							
Royal Alexandra Hosp.								25.0% 5			

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery
 Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

The international collaboration rates of the University of Alberta were higher than both the intra- and inter-provincial rates in all fields except Pediatrics and Surgery. The intra-provincial collaboration rate of the University of Calgary was also superior to its international rate in both these fields while the inter-provincial rate surpassed the foreign collaboration rate in Surgery and Cardiovascular System. By comparison, intra- or inter-provincial collaborations prevailed for most other Albertan institutions.

6 Conclusion

From 1982 to 2005, the largest numbers of papers were published in the research areas of Biochemistry, Pharmacology & Pharmacy, and Immunology at the Albertan, Canadian, and world levels. In two of these 3 specialties, Alberta held a commanding position. In Immunology, Alberta ranked first overall in the multicriteria ranking among leading Canadian provinces while it consistently ranked second over Ontario and BC in Pharmacology & Pharmacy during the last four six-year periods. Alberta also outperformed Canada and the world in terms of specialization and per capita papers in both of these specialties. In general, its impact has also been comparable to that of Canada and above the world level across the last four six-year-periods. However, there is room for Alberta to increase its output in Immunology and its output and impact in Pharmacology & Pharmacy in order to maintain its leading position.

The positioning of Alberta in Biochemistry was not as favourable. Indeed, the multicriteria ranking of Alberta in Biochemistry went from first to third position between 1982–1993 and 1994–2005. This situation mostly resulted from Alberta being unable to sustain the progress of other provinces in this field. The improvement of Alberta's position in Biochemistry between the 1994–1999 period and the 2000–2005 periods, mostly due to an increase in impact, points to possible progress in this field.

Among the other specialties, the performance of Alberta was also solid in Cardiovascular System and Physiology. In both specialties, Alberta improved its multicriteria ranking from third position in the first period to the top position in 2000–2005 and across the entire 1982–2005 period. More notable were the important increases in specialization and papers per capita. In both specialties, these two indicators were well above the world and Canadian levels in the most recent six-year period. Although, the impact of Albertan papers remained above world level for the entire 24-year period in Cardiovascular System and Physiology, recent decreases in their ARIF are worrisome.

Consistent with the importance of these fields for Alberta in number of papers, it is also in 4 of these 5 specialties that the most active Albertan researchers and the highest number of collaborations were found. Most top ranking authors from Alberta were active in Cardiovascular System and Biochemistry. Among the 5 fields, only Physiology had no Albertan researchers with at least 20 publications between 2000 and 2005. It was generally in these same fields that the Albertan institutions had their highest number of collaborations with Canadian and international organizations. Interestingly, Alberta had extended collaboration networks in two of its weakest specialty fields: Pediatrics and Oncology.

Between 1982 and 2005, Alberta also improved its position in Cell Biology and Surgery. Despite fluctuations in SI, ARIF, and papers per capita, an upward trend characterized all three indicators in Cell Biology over the 24-year period. As a result, the multicriteria ranking of Alberta in this field rose from third position in the first period to the top position in the latest six-year period and overall (1982–2005). Although the impact and papers per capita of Alberta in Cell Biology were well above those of Canada and the world in the most recent six-year period, Alberta's specialization in this field remained below the world level overall. However, this situation could change since the most recent SI

value (2000–2005) indicates that Albertan activity in this field now exceeds that of the world. In terms of impact, Alberta could benefit from strategies aimed at augmenting its output in this field as research intensity has decreased in the most recent six-year period.

Even though Alberta repeatedly ranked last in Surgery through the multicriteria ranking, it gained ground in this field over its provincial, Canadian, and world counterparts between 1982 and 2005. Notably, its position improved significantly between the last two six-year periods. Although Alberta's research intensity (SI) was still well below world level in the most recent six-year period, the gap with Canada and leading Canadian provinces was reduced over the entire 24-year period. As for the impact, it remained slightly below the Canadian average, but Alberta's position relative to Canada and the world is improving. Accordingly, Alberta should sustain this growth in both indicators to continue closing the gap with Canada and the world.

The outlook for Alberta in the other four fields is less encouraging. After occupying the leading position in the first three periods in the multicriteria ranking, Alberta fell to the second position in Microbiology for the 2000 to 2005 period. The specialization of Alberta in this field has fallen continuously across all four six-year periods but has remained well above Canadian and world levels for the 2000–2005 period. The volume of papers per capita stayed mostly unchanged throughout the entire period but also well above these benchmarks. As for the impact of papers from Albertan researchers in Microbiology, it fluctuated slightly above Canadian and world levels until the last period, when it fell below these benchmarks. Thus, Alberta could benefit from efforts aimed at increasing both its research output and the impact of its papers in this area.

In Pediatrics, Alberta has repeatedly ranked third or fourth in the multicriteria ranking. After increasing its level of specialization in this domain over the first three six-year periods, it fell back below Canadian and world levels in the 2000–2005 period. A similar trend was observed in papers per capita, with Alberta staying above Canadian and world levels across the entire 24-year period. Overall, the impact of Alberta in Pediatrics remained generally stable and well above the world. However, only in the last period was the province able to surpass the Canadian level. Hence, Alberta would benefit from efforts aimed at strengthening both indicators, but especially specialization.

The position of Alberta leaves something to be desired in Genetics and Oncology. In these two fields, which are among the most active in Canada and the world, Alberta went from the first position in the early 1980s in a multicriteria ranking to the fourth for the last three periods and overall (1982–2005). This was mainly the result of a downward trend in the specialization of Alberta. In both fields, Alberta went from above the levels of leading provinces and Canada in the first period to being below these same levels in 2000–2005. In the volume of papers per capita, Alberta remained above the Canadian level over the entire period, but the gap has closed. Over the 1982 to 2005 period, the impact of Alberta has remained relatively stable in both fields. While the impact of Alberta in Oncology was well above world level, it could only surpass that benchmark in one six-year period in Genetics. Relative to the national averages, Alberta's impact was generally below provincial and Canadian levels in both fields. Furthermore, the gap between Alberta and these benchmarks has generally widened during the 24-year period. Therefore, Alberta would need serious efforts aimed at increasing its impact, and above all its output, to regain leadership in Genetics and Oncology.

Appendix A - Methods

Constitution of datasets

In this study, Thomson Scientific's Science Citation Index (SCI) was used to produce statistics on 11 specialties of health research. SCI currently indexes approximately 3,700 of the world's leading scholarly science and technical journals. SCI was chosen principally because each paper indexed in this database includes all authors and their institutional affiliations, which allows for the computation of collaboration between various entities (e.g., countries, institutions, and researchers). Also, SCI has an extensive multi-disciplinary coverage in the NSE (e.g., biological sciences, chemistry, mathematics, physics, and engineering), allowing for field comparisons, and it includes the cited references of each document it indexes (e.g., article, chapter, or other entity published in a journal or book series), which is an essential tool to derive measures of scientific journal impact.

These publications are considered to be the most important peer-reviewed journals in their respective fields and account for approximately 90% of citations to journals in SCI. Overall, SCI coverage of the relevant scientific literature (i.e., literature that is used [cited] by the scientific community) is quite comprehensive, as it indexes at least 75% of the cited references (e.g., articles, book chapters, and books) it contains¹. In order to produce bibliometric data, three document types deemed to represent original contributions to scientific knowledge were used—articles, notes, and reviews. In this report, articles, notes, and reviews are collectively referred to as “papers”.

The dataset for each specialty was constructed by retrieving papers published in specialist journals of each specialty. Although the use of a set of journals is imperfect, mainly because it necessarily misses papers that were published in more general journals (e.g., *Nature*, *Science*) and in journals related to other disciplines, this approach is simple and provides a strong basis for comparison between countries and institutions, and for the analysis of time series. The complete SCI database constitutes in itself a dataset for the NSE with which specialties are compared in order to investigate potential divergences in the evolution of the field relative to the sciences in general.

Scientometric indicators

Statistics were produced based on the following indicators:

Number of papers: Number of scientific papers written by authors associated with geographic areas (e.g., countries and cities, based on author addresses), sectors, or organizations.

Number of papers per capita: The number of papers at the province level is weighted per capita using population statistics produced by Statistics Canada from census data.

Specialization index (SI): This is an indicator of the intensity of research of a given geographic or organizational entity (e.g., a country) in a given research area (e.g., domain, field) relative to the

¹ Henk F. Moed. 2005. *Citation Analysis in Research Evaluation*. Springer, 350 pp.

intensity of the reference entity (e.g., the world) in the same research area. The SI can be formulated as follows:

$$SI = \frac{(X_s/X_T)}{(N_s/N_T)}$$

where,

X_s = Papers from entity X in a given research area (e.g., Alberta in immunology);

X_T = Papers from entity X in a reference set of papers (e.g., Alberta in the whole database);

N_s = Papers from the reference entity N in a given research area (e.g., world in immunology);

N_T = Papers from the reference entity N in a reference set of papers (e.g., world in the whole database).

An index value above 1 means that a given entity is specialized relative to the reference entity, while an index value below 1 means the reverse.

Average relative impact factor (ARIF): This indicator is a proxy for the quality of the journals in which an entity publishes. Each journal has an impact factor (IF), which is calculated annually by Thomson Scientific based on the number of citations it received relative to the number of papers it published. The IF of papers is calculated by ascribing to them the IF of the journals in which they are published. Subsequently, to account for different citation patterns across fields and subfields of science (e.g., there are more citations in biomedical research than mathematics), each paper's IF is divided by the average IF of the papers in its subfield to obtain a Relative Impact Factor (RIF). The ARIF of a given entity is obtained by taking the average of RIF of papers belonging to it. If the ARIF is above 1, it means that an entity scores better than the world average; if it is below 1, it means that on average, an entity publishes in journals that are not cited as often as the world average.

Inter-institutional collaboration rate: This is an indicator of the relative importance collaboration with other institutions (scientific papers co-authored by researchers from different institutions). The rate is calculated by dividing the number of papers of an entity (i.e., country or institution) with at least one institutional address other than the entity in the address field, by the entity's total number of papers.

Inter-provincial collaboration rate: This is an indicator of the relative importance collaboration with other provinces (scientific papers co-authored by researchers from different provinces). The rate is calculated by dividing the number of papers of an entity (i.e., the province of Alberta) with at least one author based in another province, by the entity's total number of papers.

International collaboration rate: This is an indicator of the relative importance collaboration with other countries (scientific papers co-authored by researchers from different countries). The rate is calculated by dividing the number of papers of an entity (i.e., the province of Alberta) with at least one author based in another country, by the entity's total number of papers.

Visualization of collaboration networks

A square matrix was built from the number of papers co-authored by all pairs of the top institutions in the period 1994–2005. Only institutions with at least 12 collaborations with Albertan institutions over the 12-year period are displayed. The software programs UCINET and NetDraw (Analytic Technologies) were used to process data and produce a representation of the strength of the relationships between the top institutions in the different specialties. A "spring-embedding" algorithm was used to establish the relative locations of the institutions in the graphic representation. Each node consists of an institution represented by a circle with a size proportional to its total number of papers in collaboration with Albertan institutions. Links between nodes represent collaboration between institutions. Only links of six papers or more in collaboration for the 12-year period are depicted. The width of the links is proportional to the number of collaborations between the two institutions. Some minor modifications were made to the final network to increase readability.

Appendix B – Scientific output of BC, Ontario, and Quebec

Table XXI Number of papers from BC, Ontario, and Quebec, in 11 specialties and by six-year period, 1982–2005

Prov.	Specialty	1982-1987	1988-1993	1994-1999	2000-2005	% of growth*
British Columbia	BCM	565	858	1,073	1,247	120.7%
	CVS	67	133	211	292	335.8%
	CLB	111	127	157	191	72.1%
	GEN	199	379	533	648	225.6%
	IMM	177	357	514	542	206.2%
	MCB	168	248	294	306	82.1%
	ONC	197	275	444	608	208.6%
	PED	57	112	82	124	117.5%
	PHM	464	477	515	586	26.3%
	PHY	175	275	291	283	61.7%
	SUR	130	174	201	240	84.6%
Ontario	BCM	2,621	3,411	3,847	4,325	65.0%
	CVS	489	710	961	1,519	210.6%
	CLB	585	528	633	660	12.8%
	GEN	705	1,194	1,579	1,548	119.6%
	IMM	954	1,186	1,584	1,580	65.6%
	MCB	817	947	872	863	5.6%
	ONC	809	1,066	1,524	1,966	143.0%
	PED	353	370	433	506	43.3%
	PHM	1,689	1,813	1,847	1,817	7.6%
	PHY	668	1,001	1,221	1,203	80.1%
	SUR	912	986	1,137	1,151	26.2%
Québec	BCM	1,400	2,264	3,024	2,931	109.4%
	CVS	316	458	667	1,052	232.9%
	CLB	311	362	415	469	50.8%
	GEN	255	599	966	844	231.0%
	IMM	519	753	966	898	73.0%
	MCB	284	503	519	564	98.6%
	ONC	288	468	627	798	177.1%
	PED	189	205	241	215	13.8%
	PHM	1,103	1,258	1,468	1,431	29.7%
	PHY	456	580	695	630	38.2%
	SUR	458	430	422	419	-8.5%

BCM: Biochemistry, CVS: Cardiovascular System, CLB: Cell Biology, GEN: Genetics, IMM: Immunology, MCB: Microbiology, ONC: Oncology, PED: Pediatrics, PHM: Pharmacology & Pharmacy, PHY: Physiology, SUR: Surgery

* Growth in output between the first period (1982-1987) and the most recent period (2000-2005)

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Appendix C – Scientometric positioning

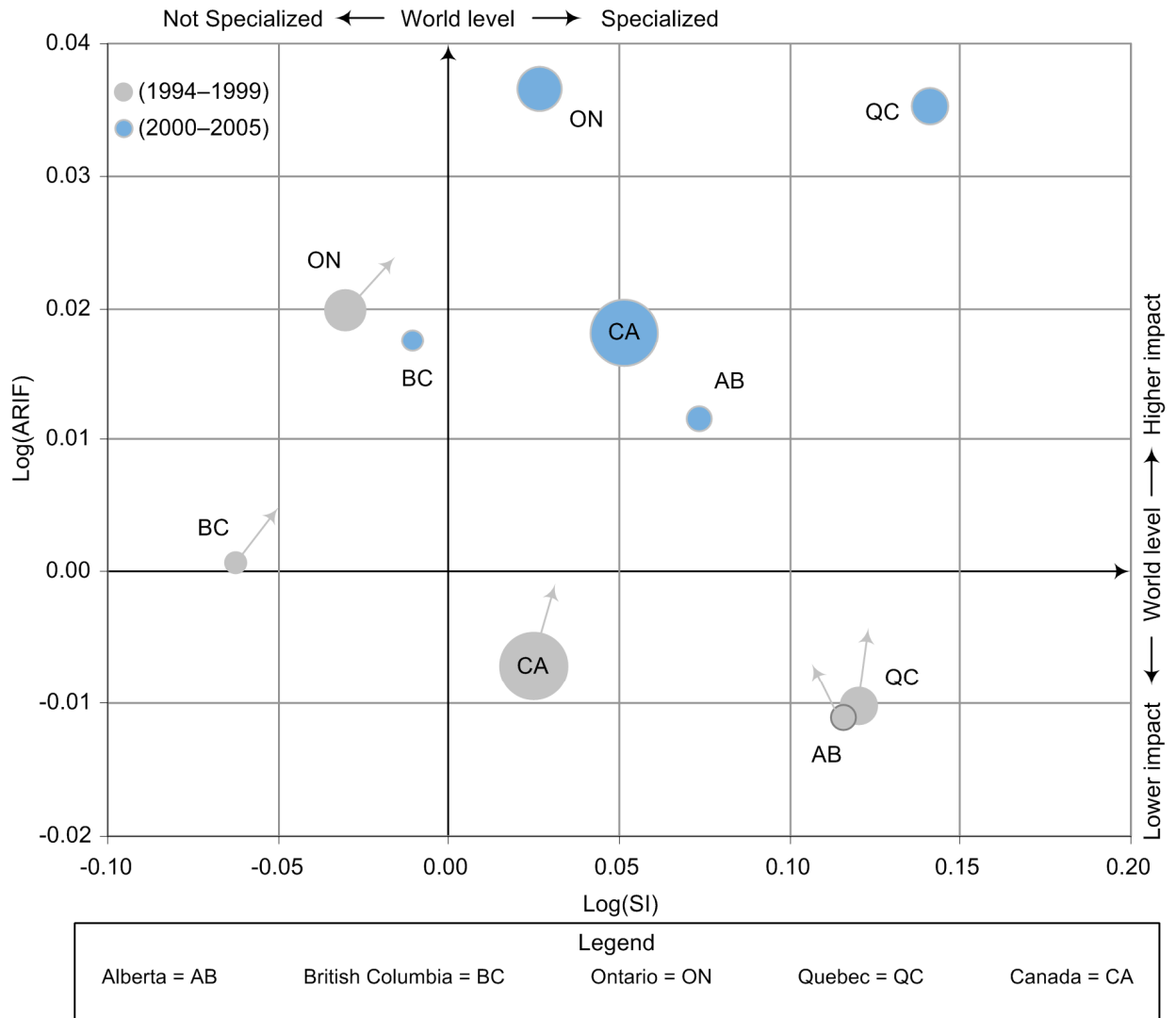


Figure 1 Scientometric positioning of provinces based on specialization and scientific impact in Biochemistry, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

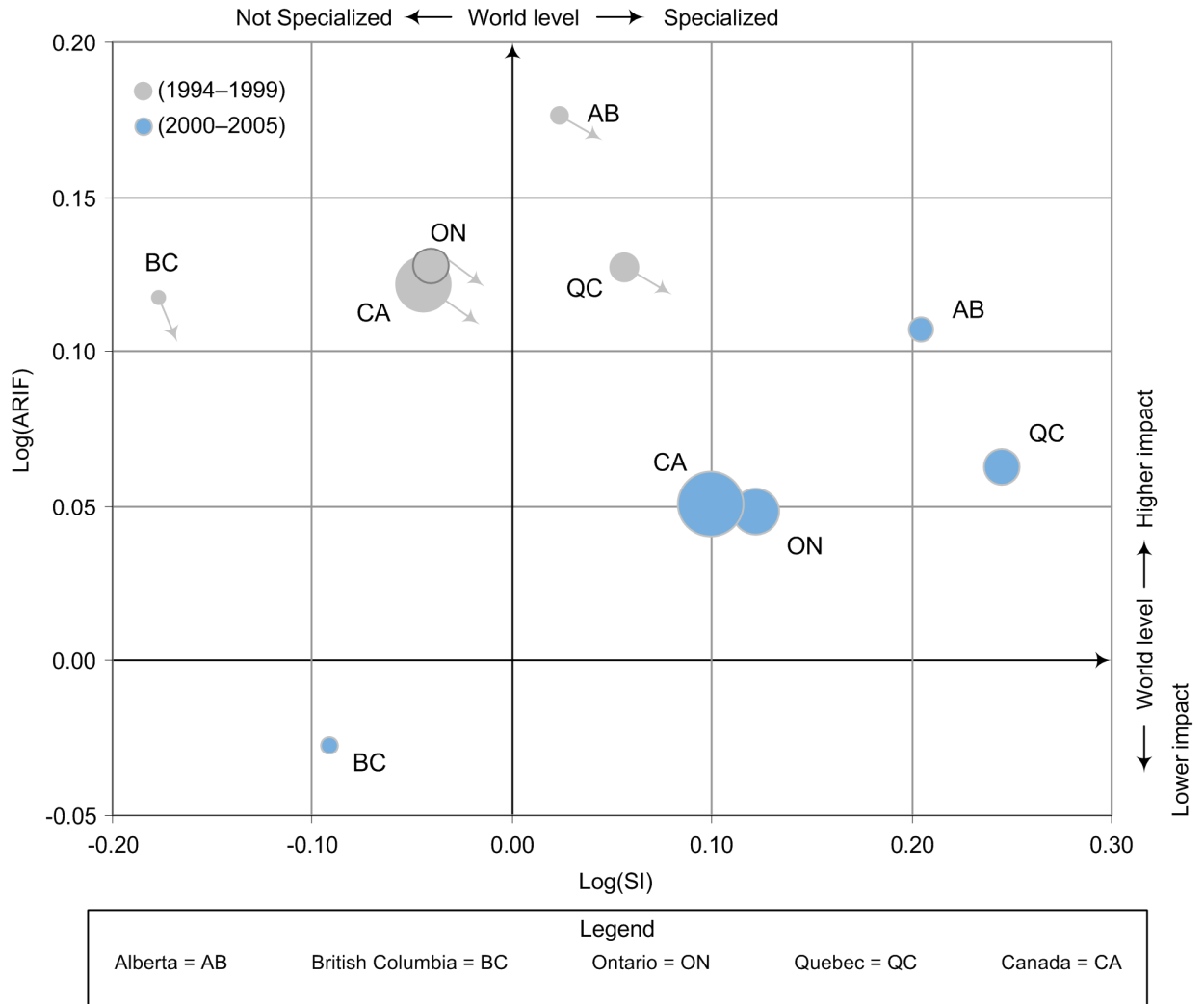


Figure 2 Scientometric positioning of provinces based on specialization and scientific impact in Cardiovascular System, 1994-1999 and 2000-2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

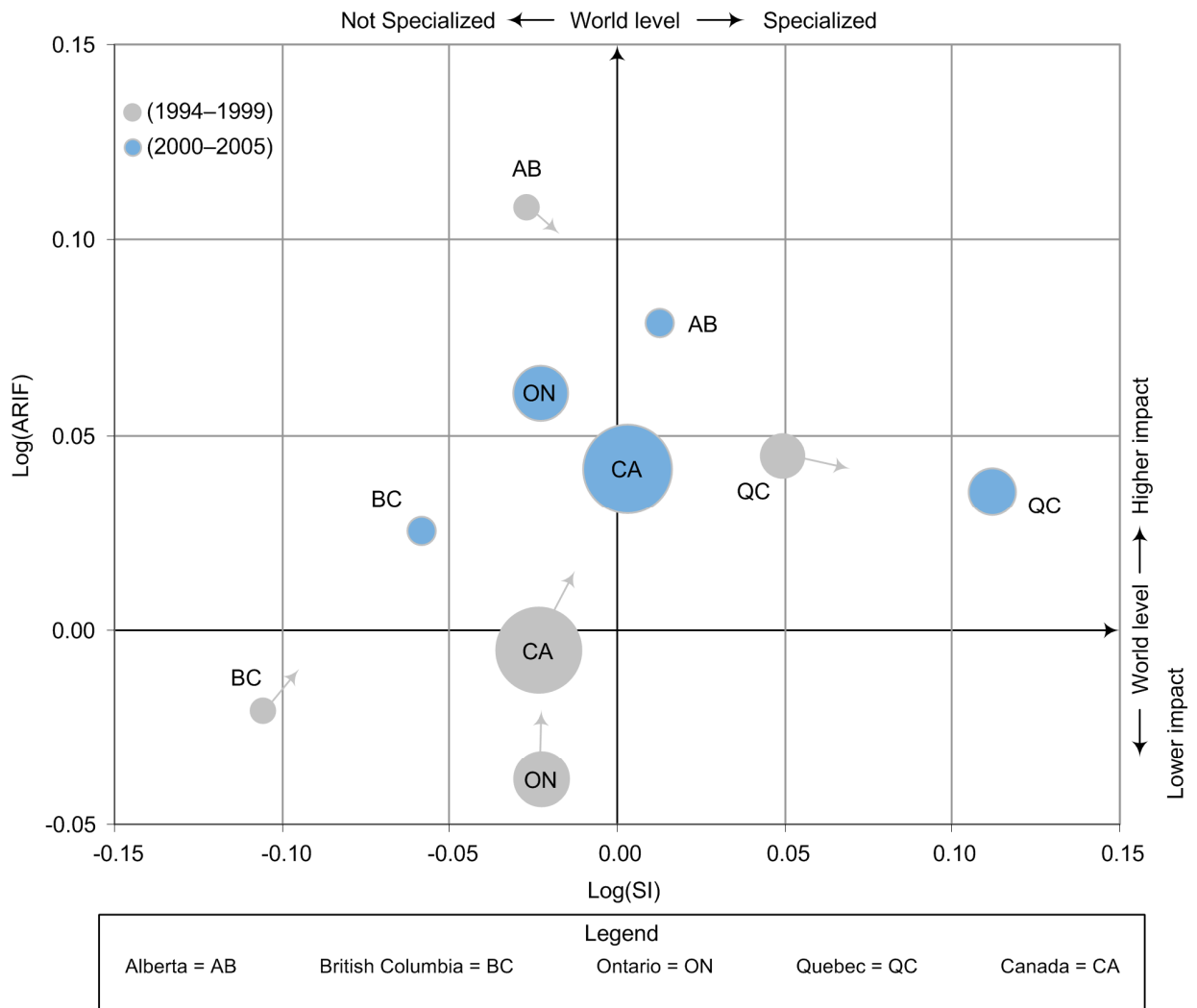


Figure 3 Scientometric positioning of provinces based on specialization and scientific impact in Cell Biology, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

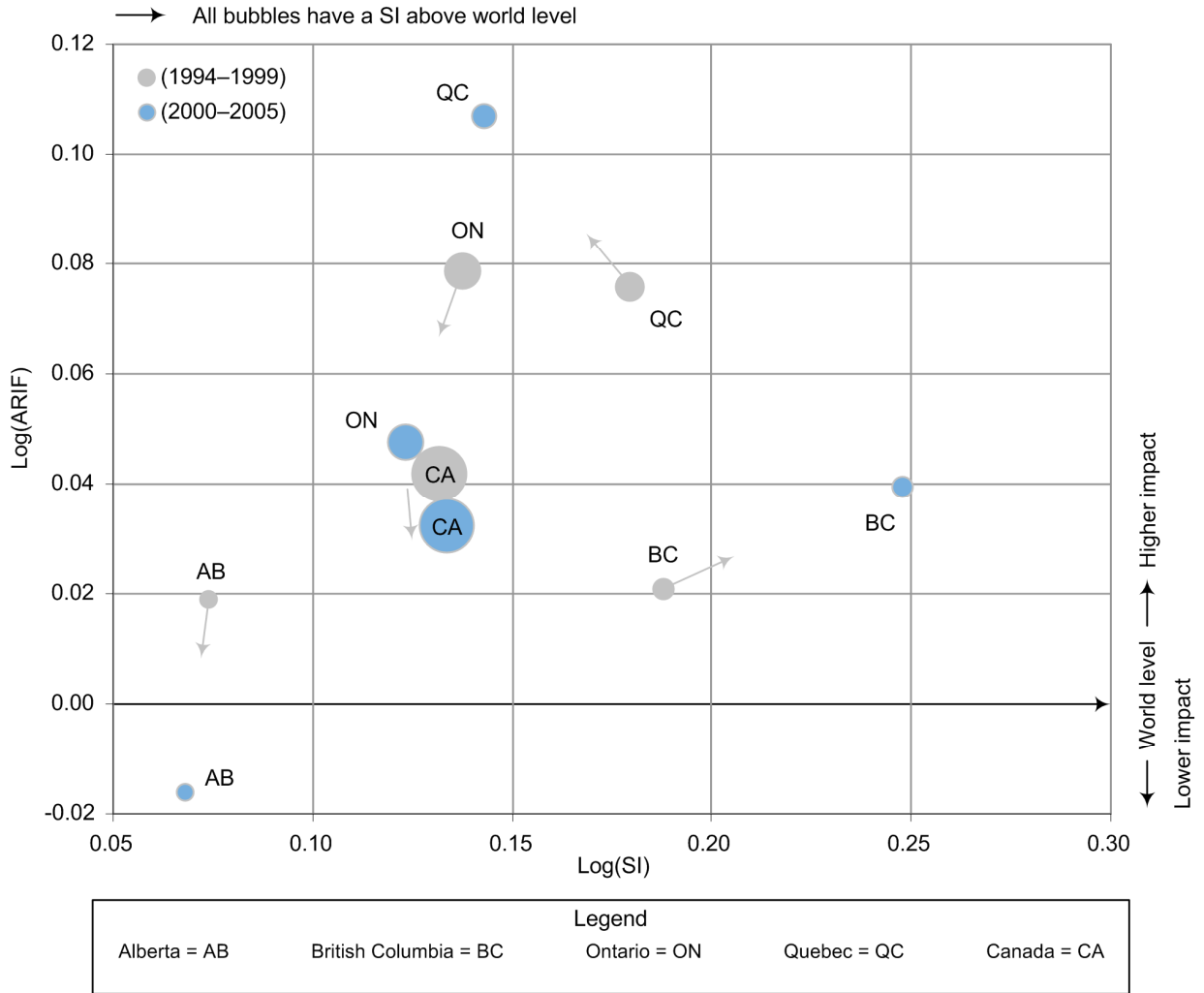


Figure 4 Scientometric positioning of provinces based on specialization and scientific impact in Genetics, 1994-1999 and 2000-2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

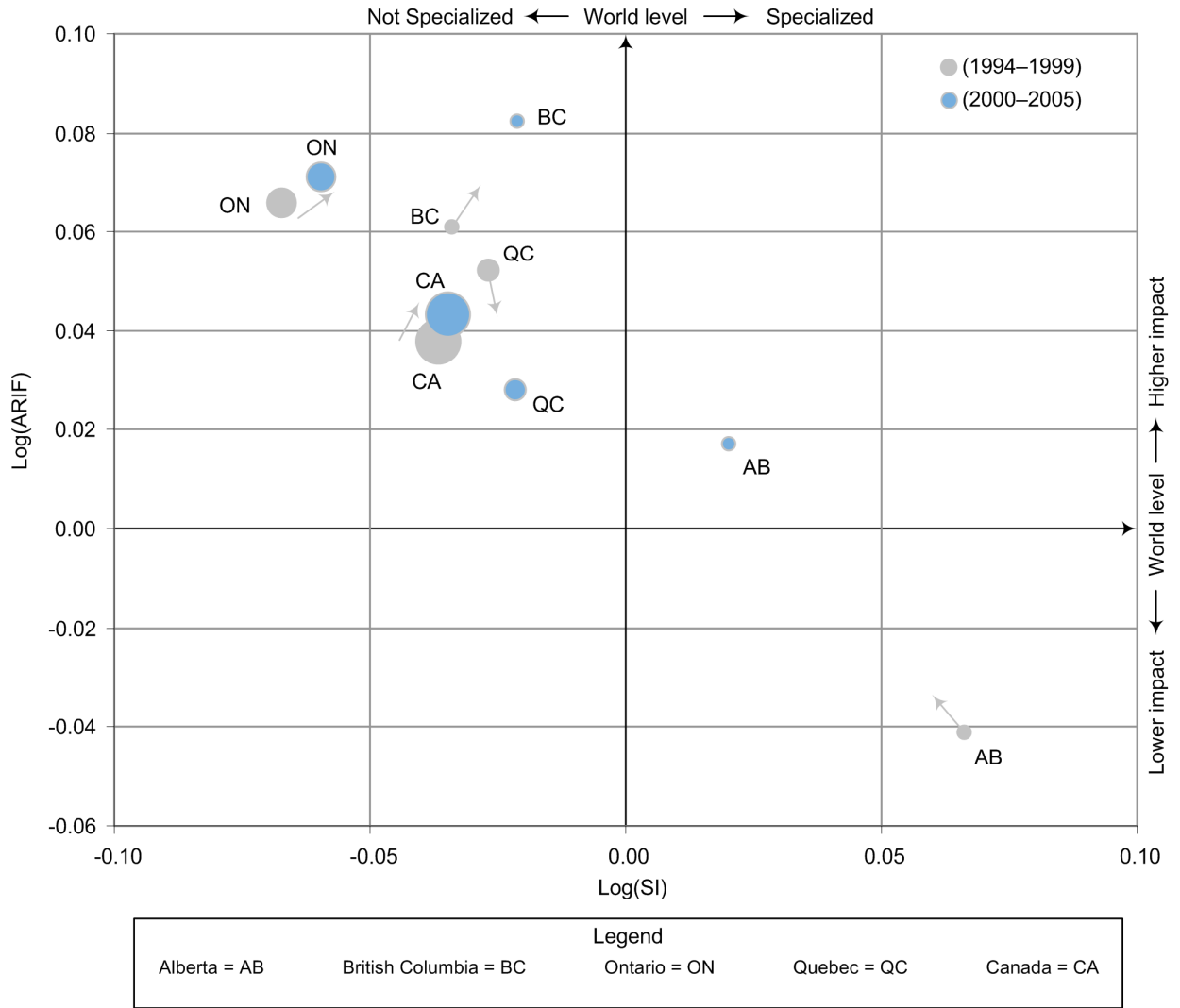


Figure 5 Scientometric positioning of provinces based on specialization and scientific impact in Immunology, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

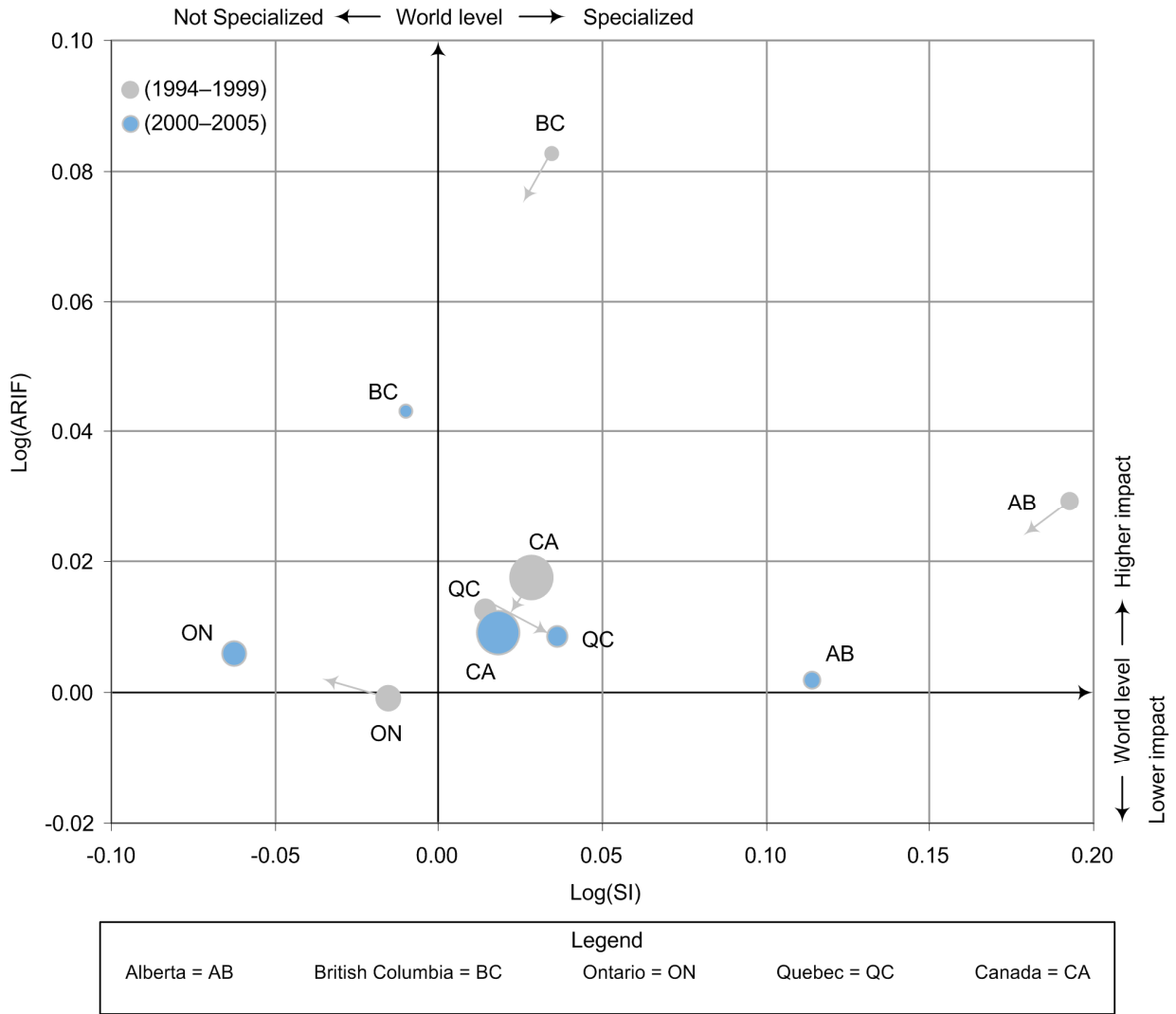


Figure 6 Scientometric positioning of provinces based on specialization and scientific impact in Microbiology, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

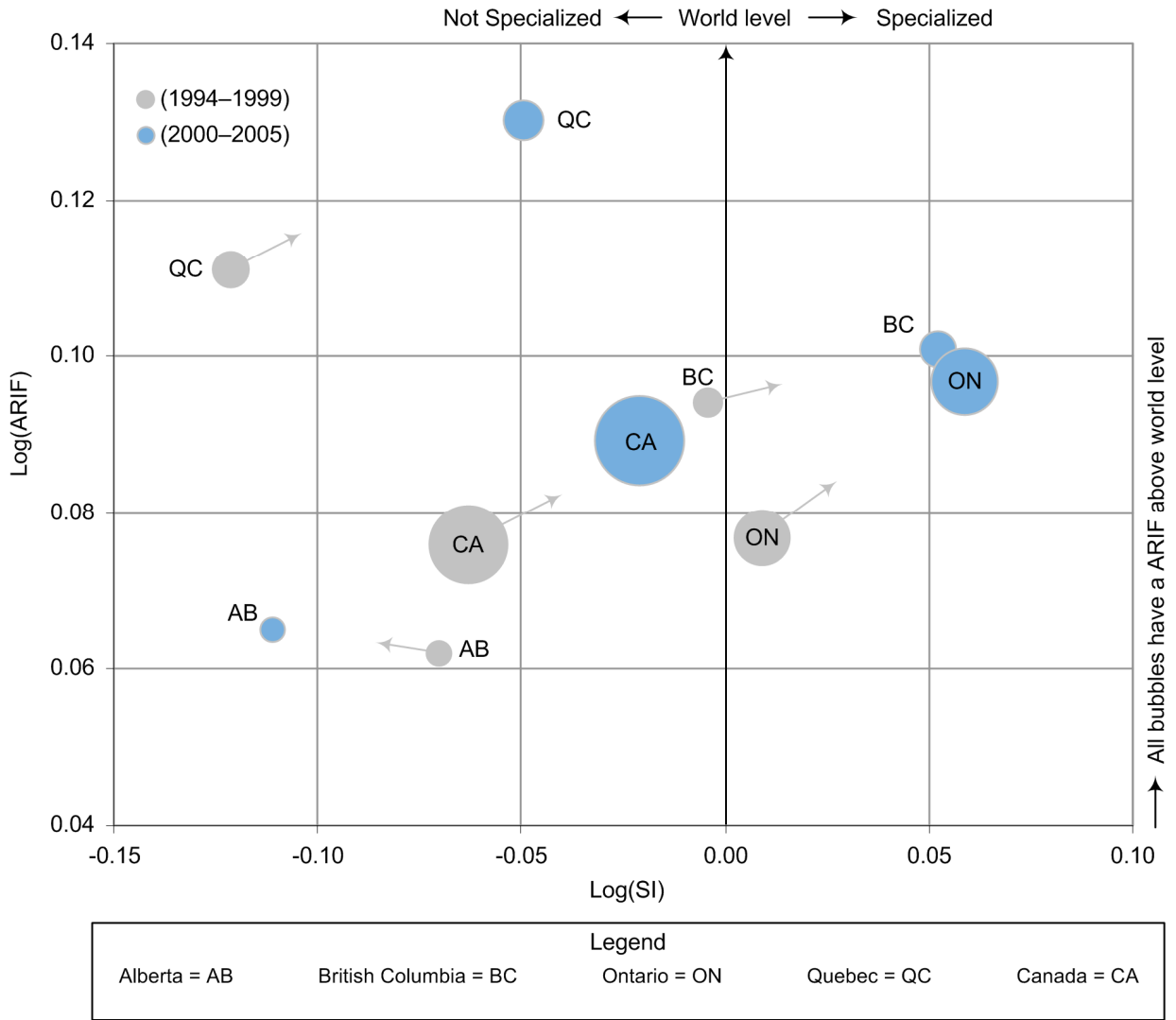


Figure 7 Scientometric positioning of provinces based on specialization and scientific impact in Oncology, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

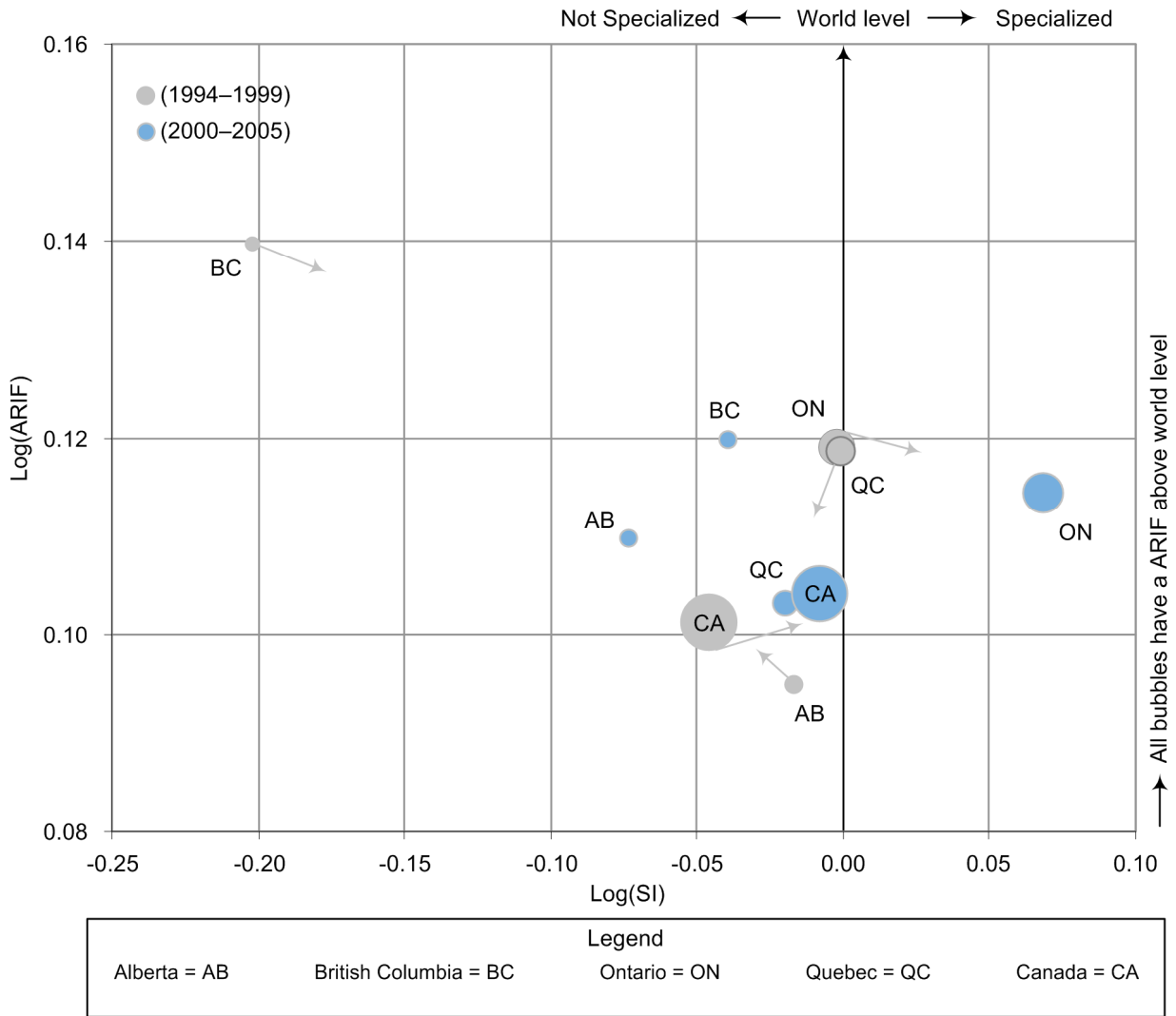


Figure 8 Scientometric positioning of provinces based on specialization and scientific impact in Pediatrics, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

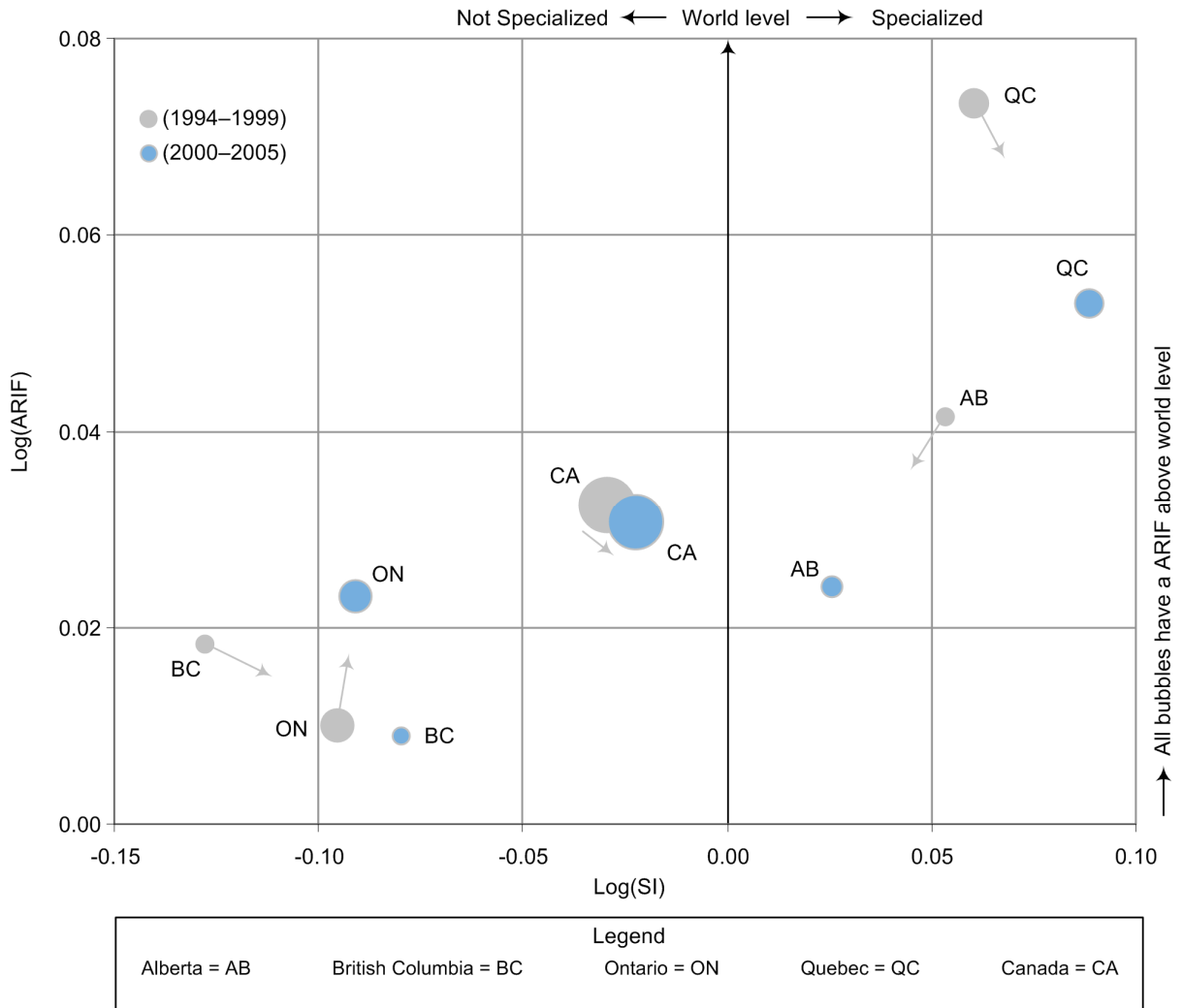


Figure 9 Scientometric positioning of provinces based on specialization and scientific impact in Pharmacology & Pharmacy, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

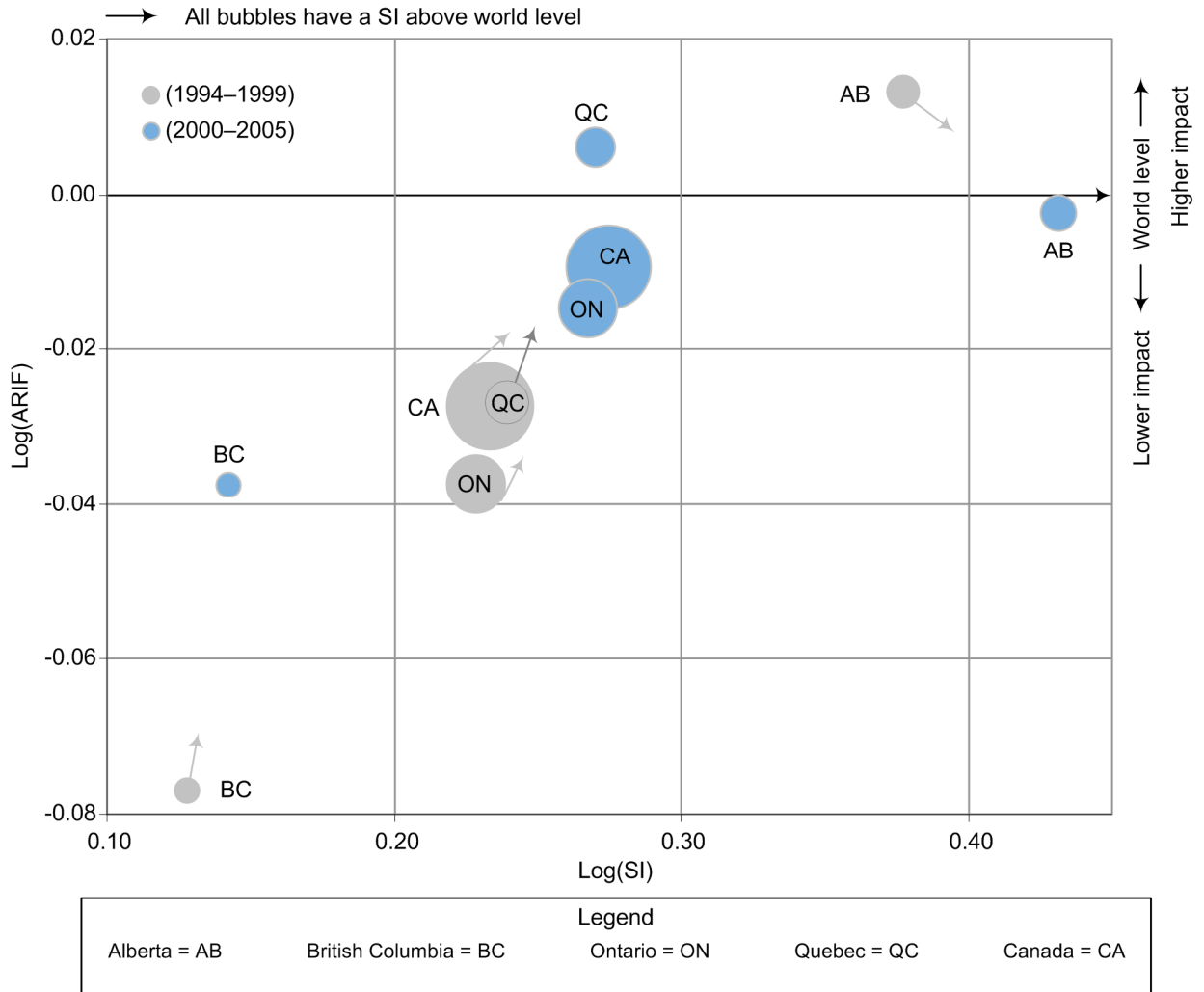


Figure 10 Scientometric positioning of provinces based on specialization and scientific impact in Physiology, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

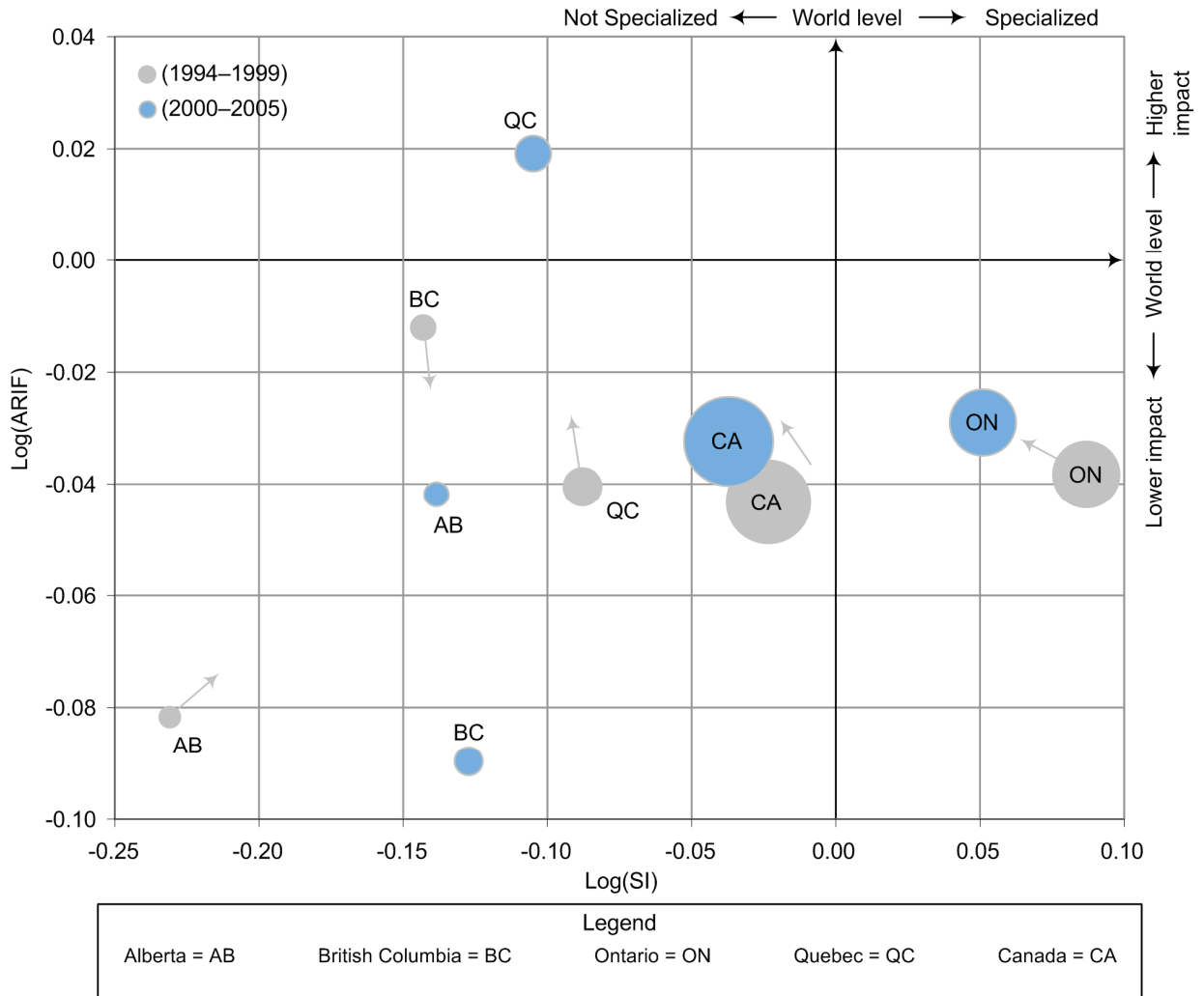


Figure 11 Scientometric positioning of provinces based on specialization and scientific impact in Surgery, 1994–1999 and 2000–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Appendix D – Inter-institutional collaboration networks

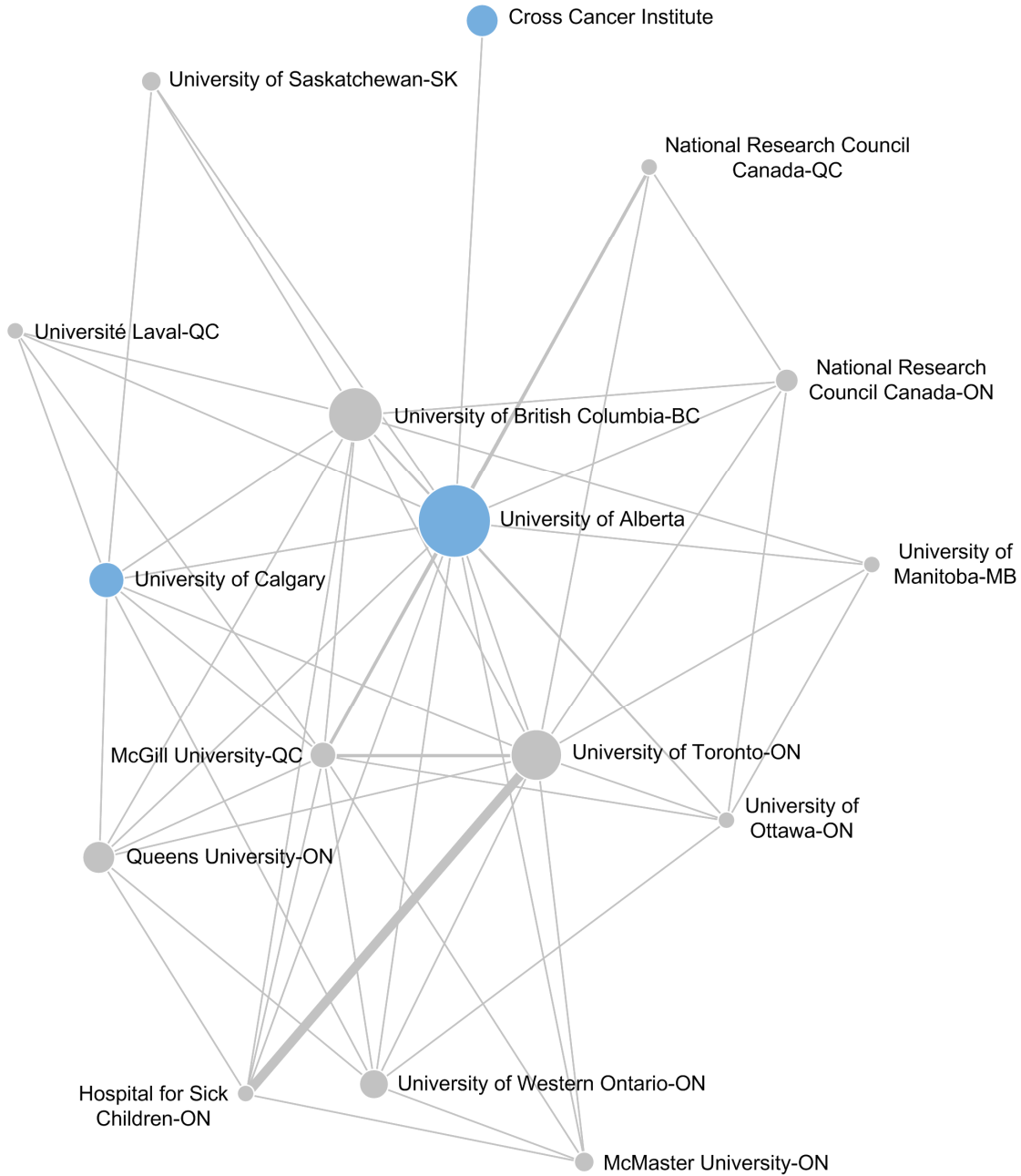


Figure 12 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Biochemistry, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

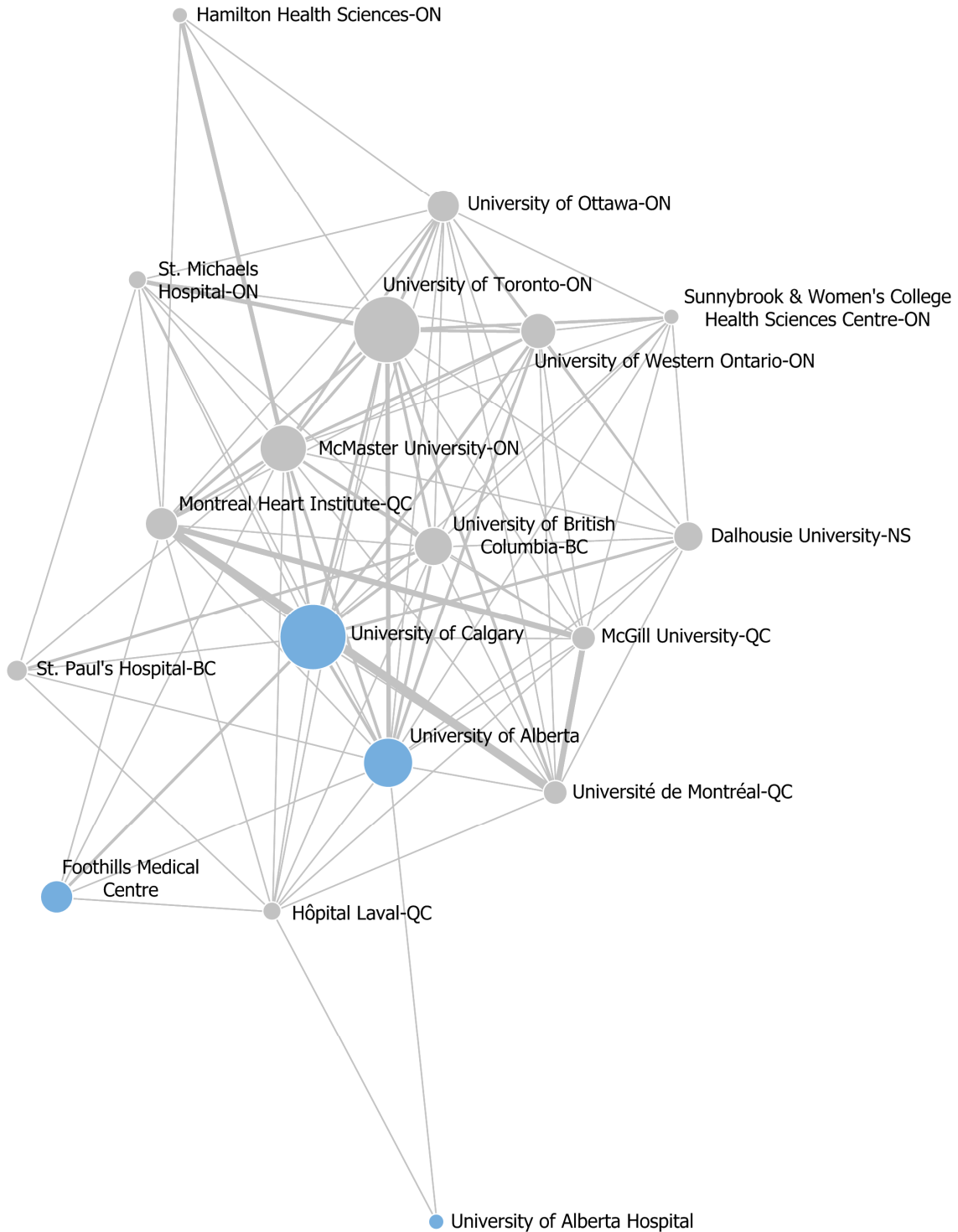


Figure 13 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Cardiovascular System, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

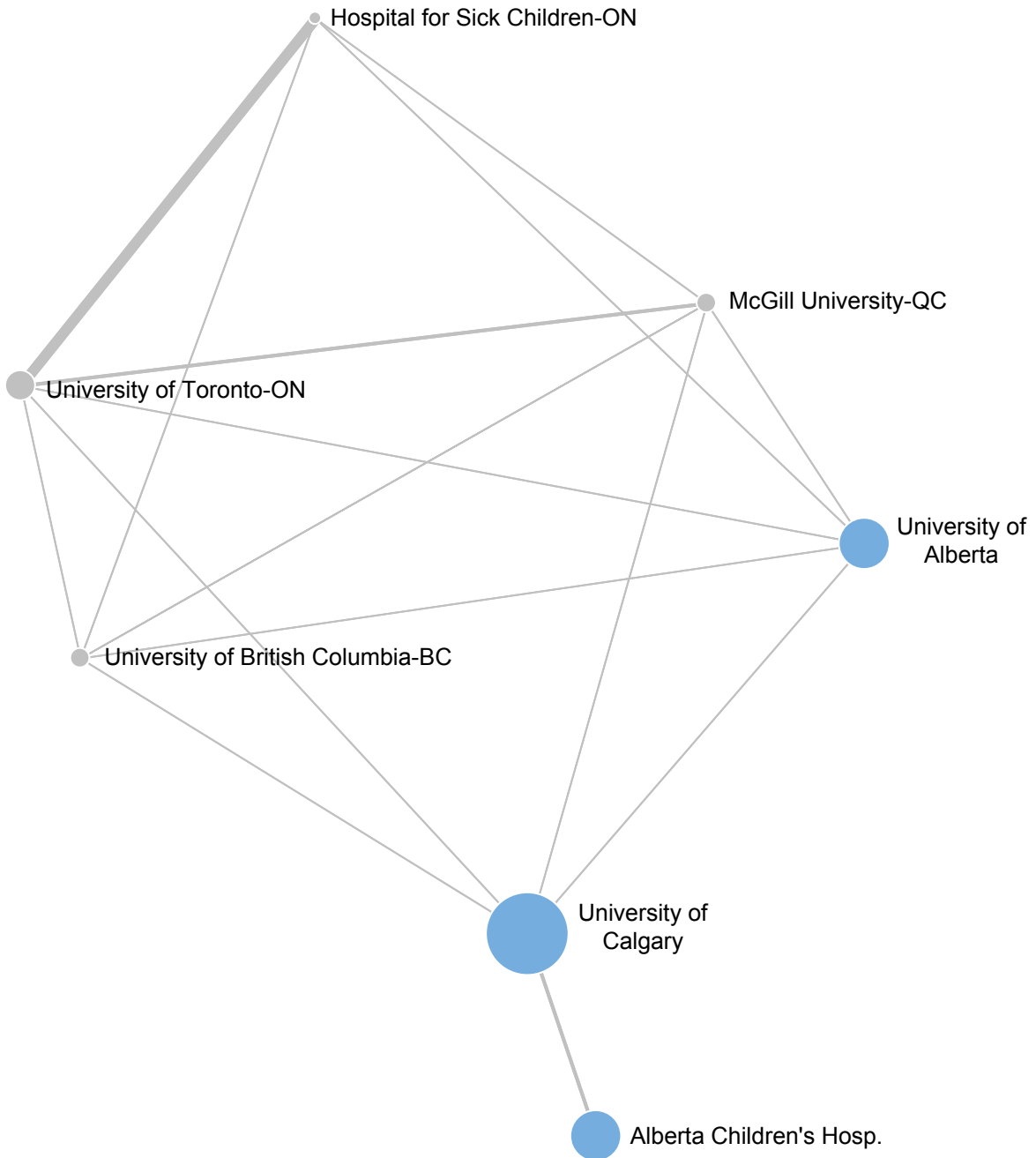


Figure 14 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Genetics, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

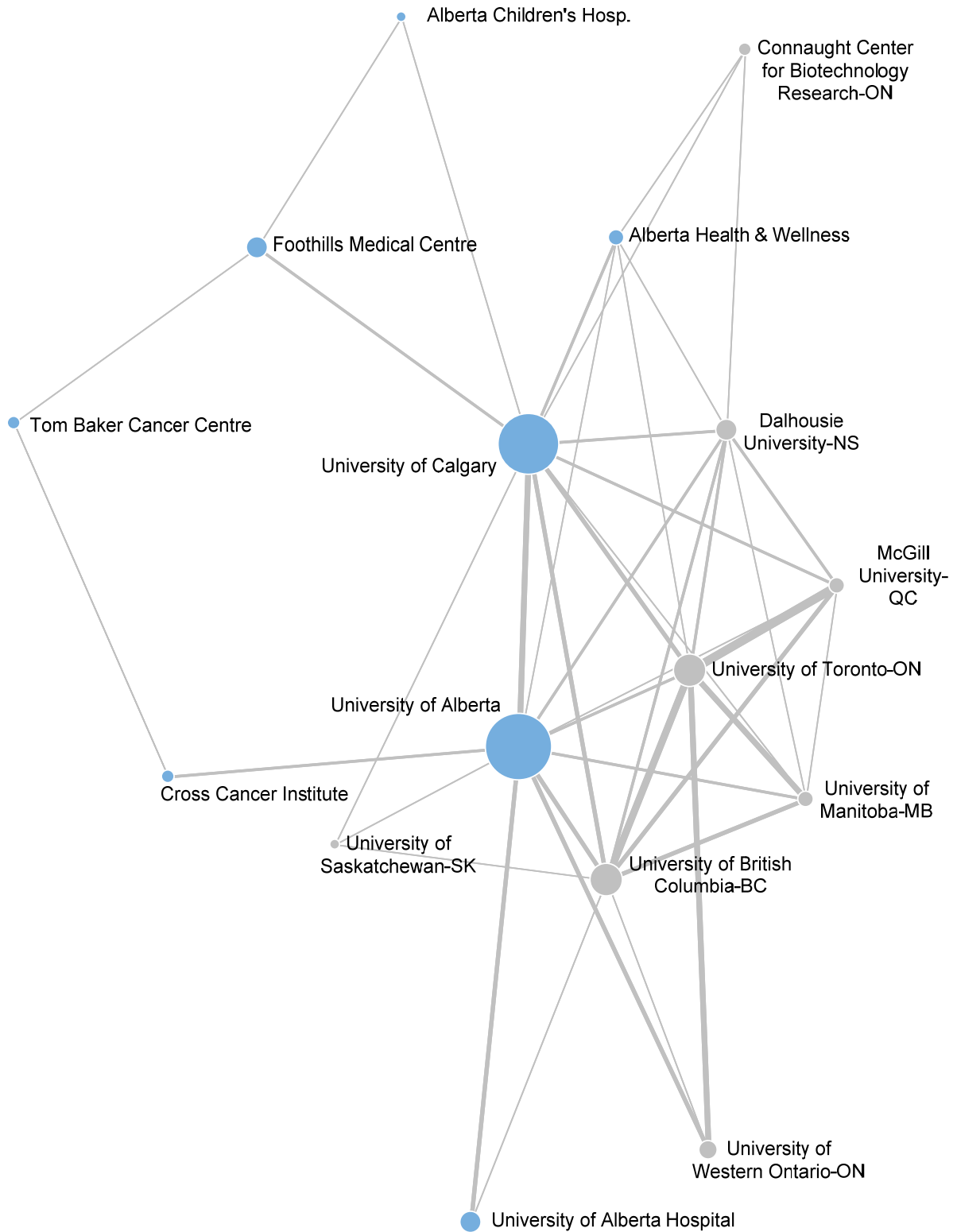


Figure 15 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Immunology, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

Scientific positioning of Alberta in health research specialties

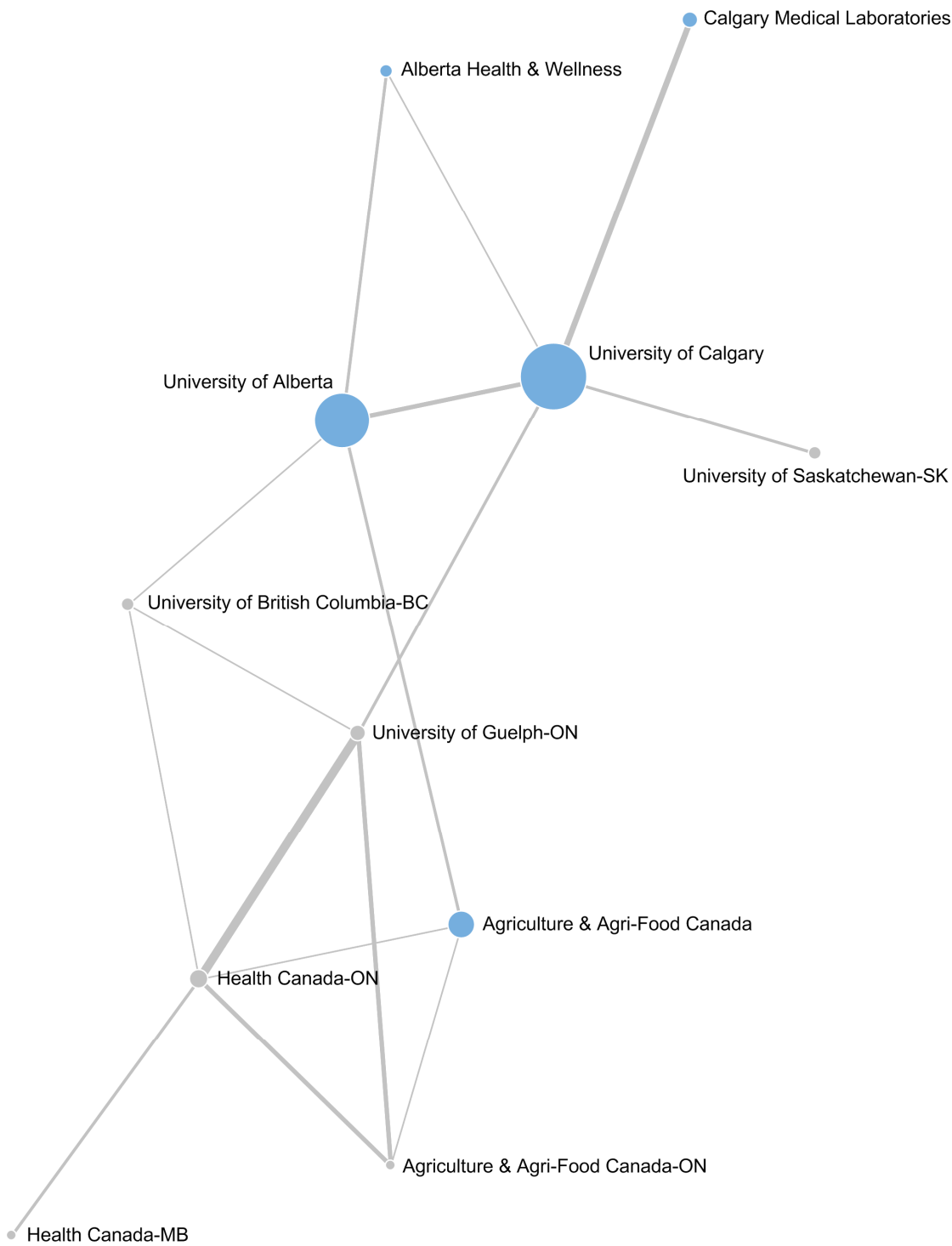


Figure 16 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Microbiology, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

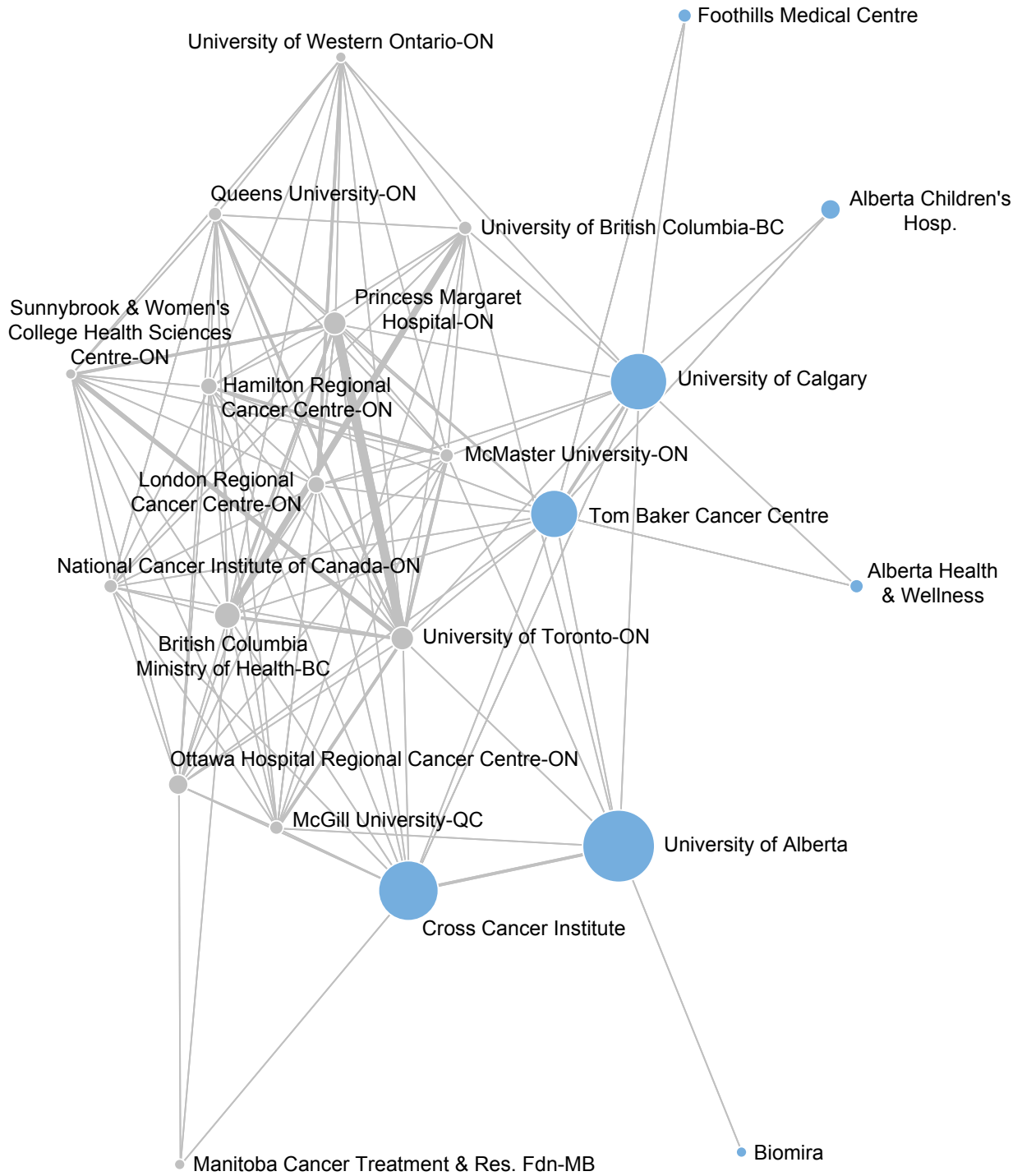


Figure 17 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Oncology, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

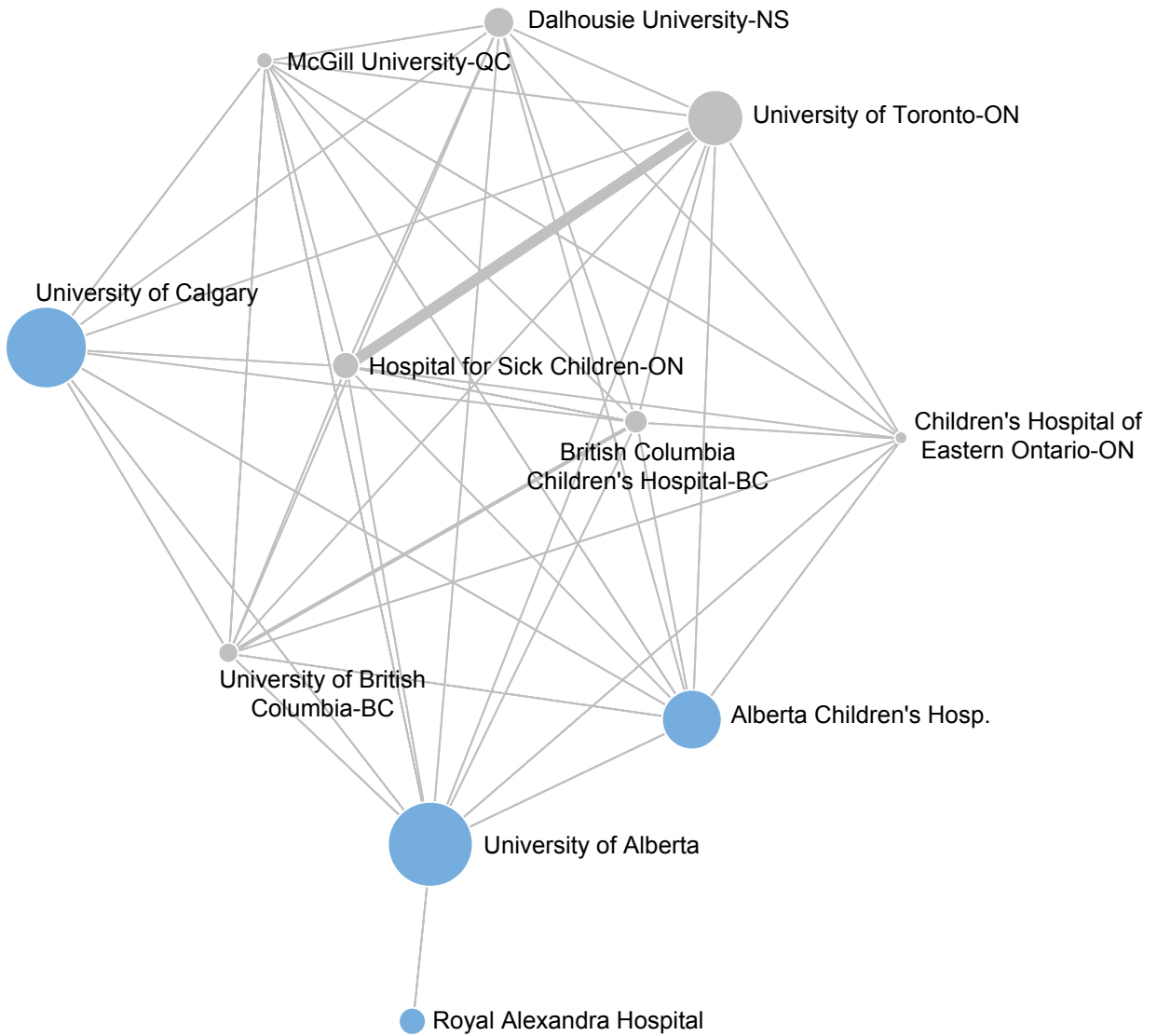


Figure 18 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Pediatrics, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

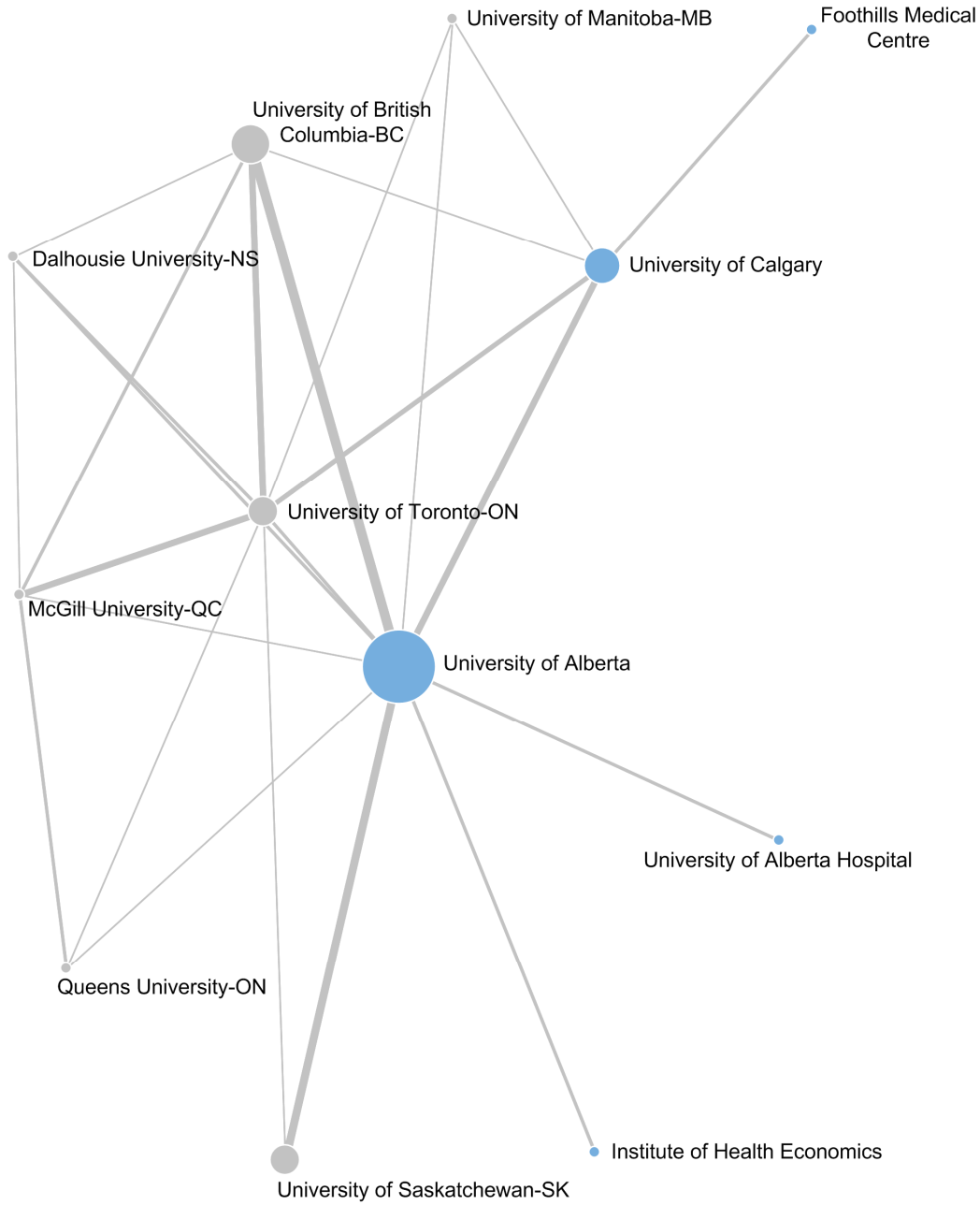


Figure 19 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Pharmacology & Pharmacy, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

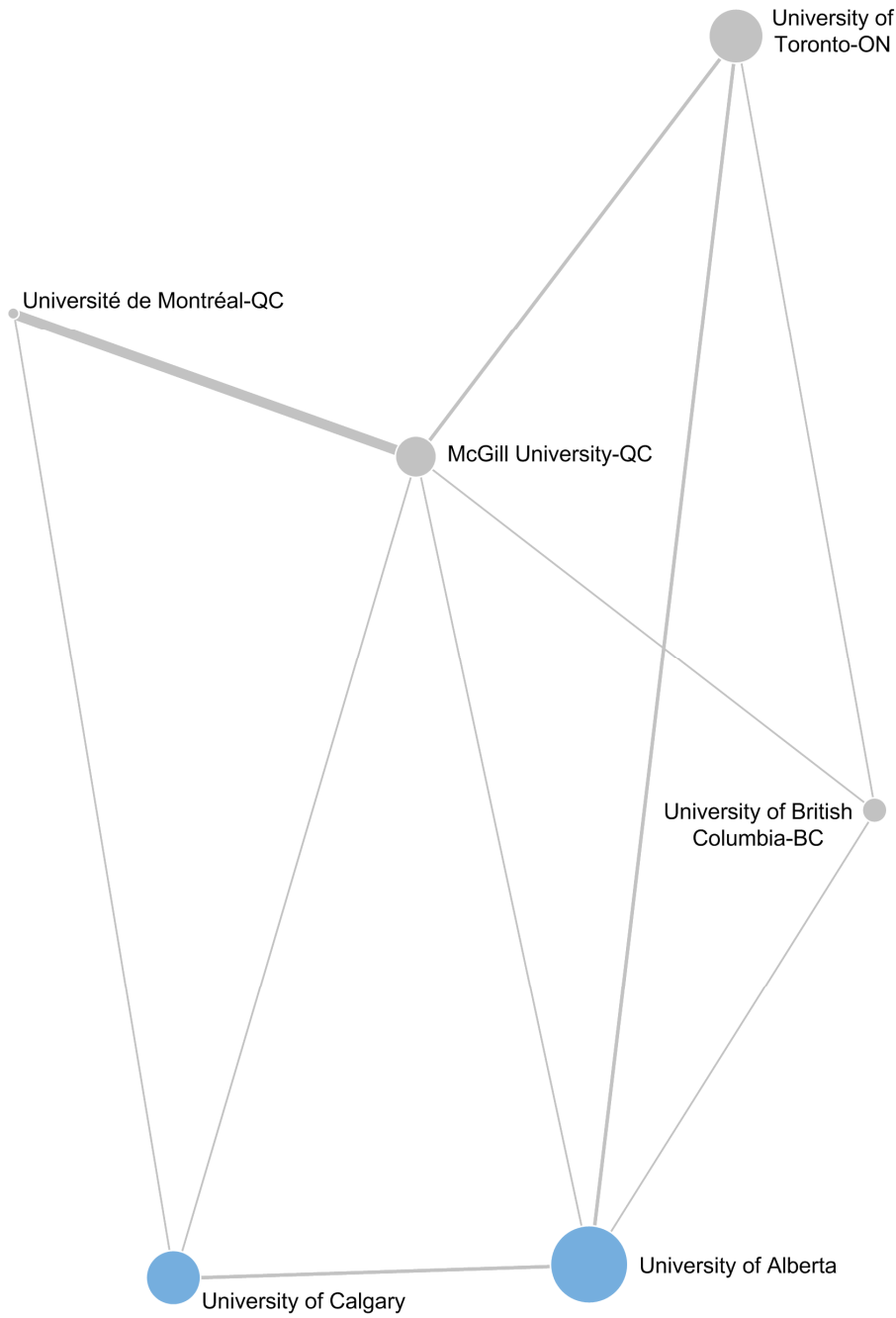


Figure 20 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Physiology, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)

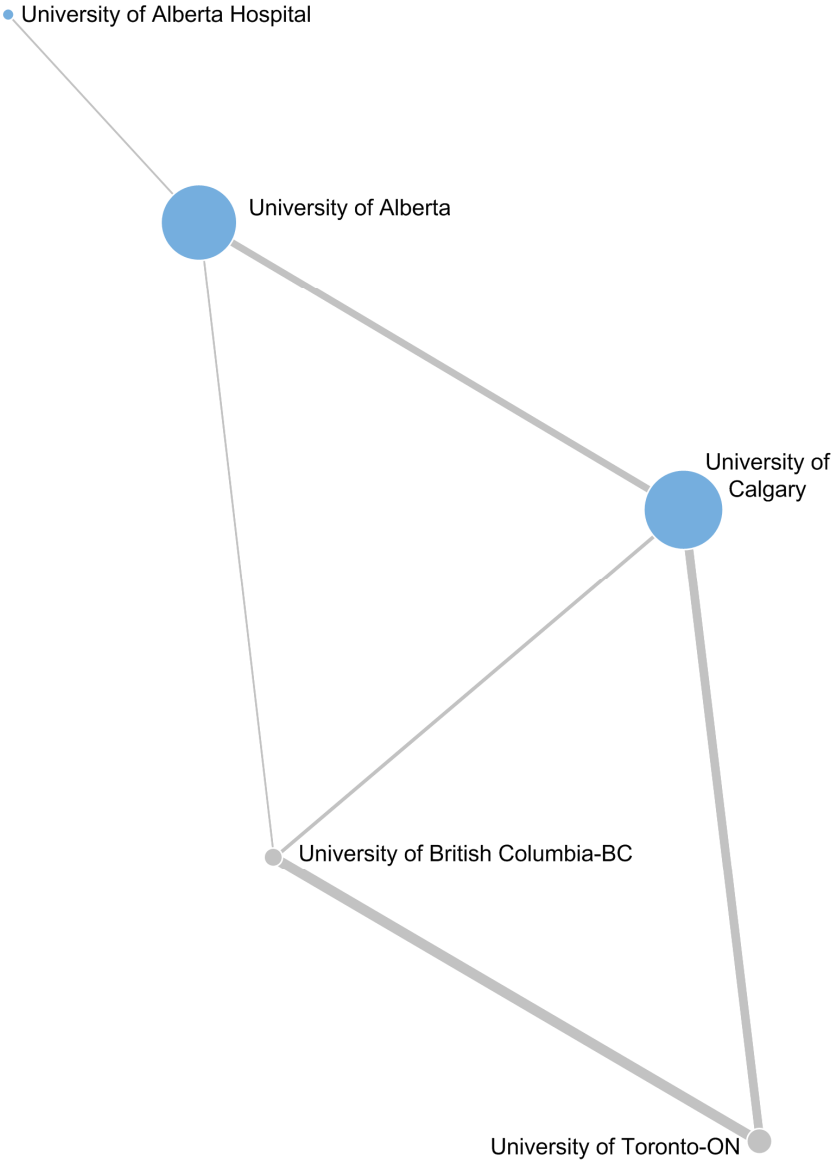


Figure 21 Inter-institutional collaborations of Albertan institutions within Alberta and Canada in Surgery, 1994–2005

Source: Compiled by Science-Metrix from the SCI database hosted by OST (© Thomson Scientific)