

## The Analysis of Co-authorship and Networks among the Korean Pathologists

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**Background:** To evaluate the characteristics of the co-authorship and its network within the Korean Pathologists' Society. **Methods:** In the KoreaMed database, 11,420 articles and 72,478 authors from 1991 to 2010 were searched. The patterns of co-authorship of the authors and institutions were analyzed to build a network matrix. The network centrality indices were measured with UCINET 6.0 and sociogram, and were drawn with Netdraw 5.0. KeyPlayer 1.44 was used for key player analysis. **Results:** The number of articles that pathologist participated in increased; however, the number of articles that the pathologists are the first author did not increase. The centrality degrees from 1991 to 2010 were 4.16% and 0.3% for the institutions and authors network, respectively. From 1991 to 2000, Seoul National University had the highest degree of centrality and was a key player. However, from 2001 to 2010, Ulsan replaced the position. For the authors, Chi, Je Geun was highest centrality author and key player during the 1991 to 2000 time period. From 2001 to 2010, Yoo, Jinyoung had the highest degree of centrality and Kim, Na Rae was a key player. Overall, most of the centrality indices were occupied by only a few institutions and authors. **Conclusions:** The network among the pathologist society is a typical small world society.

**Key Words:** Co-authorship; Network; Pathologist

Since its establishment as a specialty, pathologists have widely contributed to the advance of medicine from morphological studies (histology and cytology), to cutting edge fields such as targeted gene therapy. By its nature, pathologists make important interpretations and diagnoses. As a result, they generate valuable data for the clinical research and their research has been an integral part of pathologists' work. In particular, for academic institutions, research is the lifeline of pathology and pathologists must continue research to lead the advances of medicine. Essential to this is pathologists' ability to justify increasing financial support, while also satisfying the multiplicity of forces which drive investigators. Also, various pathology organizations and institutions will need to be strengthened to support the survival and growth of this specialty. In addition, thorough communication among pathologists and among the pathology institutions is critical to meeting these goals.

Meanwhile, the co-authorship networks analysis is important for the social network studies and have been used extensively to determine the structure of scientific collaborations and the status of individual researchers.<sup>1</sup> That is because the analysis of citations can occur without the authors knowing each other and

can span across time; however, co-authorship requires implications in the realm of social network analysis. However, in a previous network study, the pathology research field was shown to have a lower degree of centralization, which suggests that the communication in the field of pathology is not progressing.<sup>2</sup> As a result, a detailed sociometric analysis about pathologists' society would allow them to gain knowledge about their network by identifying and mapping interpretable and homogenous clusters among the authors and among the institutions. Such visualization of scientific networks is more than simply creating intriguing pictures. The images of social networks among pathologists may provide new insights about their network structure and would help them to facilitate better communication. Also, these network analyses may provide useful information for a number of stakeholders, such as medical students who want to specialize in pathology, pathology researchers with specific interests, hospital administrators, research agencies managing research funds, and governments. Therefore, we analyzed the structural characteristics of networks among the pathologists and among the institutions in order to elucidate some of this information.

## MATERIALS AND METHODS

To identify distinct homogenous clusters of co-authorship, we searched medical journals listed in the KoreaMed Database. In the database, all the articles published from January 1991 to December 2010, in which pathologists participated in, were searched. In brief, twenty years of articles with "pathology" in the affiliation field of the KoreaMed database were collected, resulting in an initial collection of 18,898 articles. Among them, departments that had similar names such as "veterinary pathology," "clinical pathology," and "dental/oral pathology" were differentiated and excluded. In total, 11,420 articles from 169 journals matching the "classic meaning of pathology" in the affiliation field were found. Among these, 3,031 articles (26.5%) had a "pathologist" as a first author. In summary, there were 72,478 consecutive authors involved, 13,270 of which were first author pathologists. We classified whole articles where a pathologist participated as PPA0, and articles in which the pathologist was first author as PPA1.

It is reasonable that scientific acquaintances can be defined as scientists who had written a paper together and were connected. Thus, the authors and institutions were considered to have links (connections) if they had co-authored a paper together. If an institution or an author positioned as the first author co-authored with another institution or person, the relationship between the former and latter was regarded as simply as a co-author regardless whether the author is a corresponding author or not because the KoreaMed database did not note a corresponding author. It was intended that social network analysis would be applied to this matrix to identify levels of inter-organizational and inter-personal communication. The treatment process of name variants of the institutions is similar to previously described methods.<sup>2,3</sup>

In brief, to analyze the network among the institutions, a 73×73 matrix was generated. Institutions with more than 5 articles published were regarded as a node. These included 40 medical schools and their hospitals, as well as 22 medical institutions. National Police and Military Hospitals were grouped as N\_Police and N\_Defense, respectively. Other general hospitals were grouped as "Hospital2," while private clinics were classified as "Clinic." The three science and technology institutes, Korea Advanced Institute of Science and Technology (KAIST), Gwangju Institute of Science and Technology (GIST) and Pohang University of Science and Technology (POSTECH), were grouped as "KGPTech." Other educational institutions were grouped as "EDU." The Korea Research Institute for Bio-

science and Biotechnology (KRIBB) and National Institute of Scientific Investigation, currently National Forensic Service (NFS, NISI) were separately used. Other national organizations such as Korea Institute of Nuclear Safety (KINS) were grouped as "GOV." Six foreign countries USA, Japan, China, Germany, Turkey, and Taipei were separately used. Countries other than those listed above were grouped as "Foreign2." Companies such as Siemens were grouped as "Company." Affiliations not otherwise classified were grouped as "#N/A."

To analyze the authors' network, the authors were analyzed according to their full name, as listed in KoreaMed. The misspellings of the authors were not corrected to prevent bias. However, a simple spacing error and using hyphen such as 'Park, YongKoo,' 'Park, Yong Koo' and 'Park, Yong-Koo' were corrected if the affiliation is recognized. On the contrary, different persons with the same full name could not be differentiated, and as a result, counted as one. As the number of authors varied from year to year, the size of the authors' matrix also varied. The smallest matrix was 213×213 in 1993, while the largest was 502×502 in 2010.

We used a social network analysis software UCINET<sup>4</sup> to measure centrality indices as suggested by Freeman.<sup>5</sup> The term centrality may denote 'how a network is structured' or 'how a node contributes to the network' and it can be characterized by the nature of the flow of information. However, the term 'centrality' is usually restricted to the idea of point centrality, while the term 'centralization' is used to refer to particular properties of the graph structure as a whole.<sup>2</sup> The term "indegree" is a count of the number of ties directed to the node; whereas, outdegree is the number of ties that the node directs to others.

Netdraw 1.44,<sup>6</sup> a social network visualization software with which graphic representation of networks (including relations and attributes) can be drawn, was used to draw a sociogram of the designated period.

We used the KeyPlayer 1.44 program<sup>7</sup> for identifying an optimal set of nodes in a network. The program performs a procedure to find sets of key players in a social network.<sup>8</sup> We also used the Distance Weighted Reach Criterion method (KPP-NEG) to identify key players for the purpose of disrupting or fragmenting the network by removing the key nodes. The basic algorithm of this method aims to lengthen the average distance between pairs of nodes by judiciously deleting key nodes with the assumption that the optimal selection of key players depends on what they are needed for.

## RESULTS

### Descriptive statistics

PPA0 increased rapidly since 1997, and plateaued after 2002. Before 1997, the number of PPA0 per year was less than 300. The number jumped up to 566 in 1997 (Table 1). Meanwhile, there was a temporary drop off in the number of articles and authors in 1999 because of the so called ‘economic crisis’ in Korea. As the number of articles increased, the number of authors also increased. The number of authors of PPA0 was 588 in 1991, which increased by almost a factor of ten (up to 5,655) in 2009. Notably, the increase of PPA0 was mostly associated with the increase of article co-authorship with other department inside the same institution (Fig. 1).

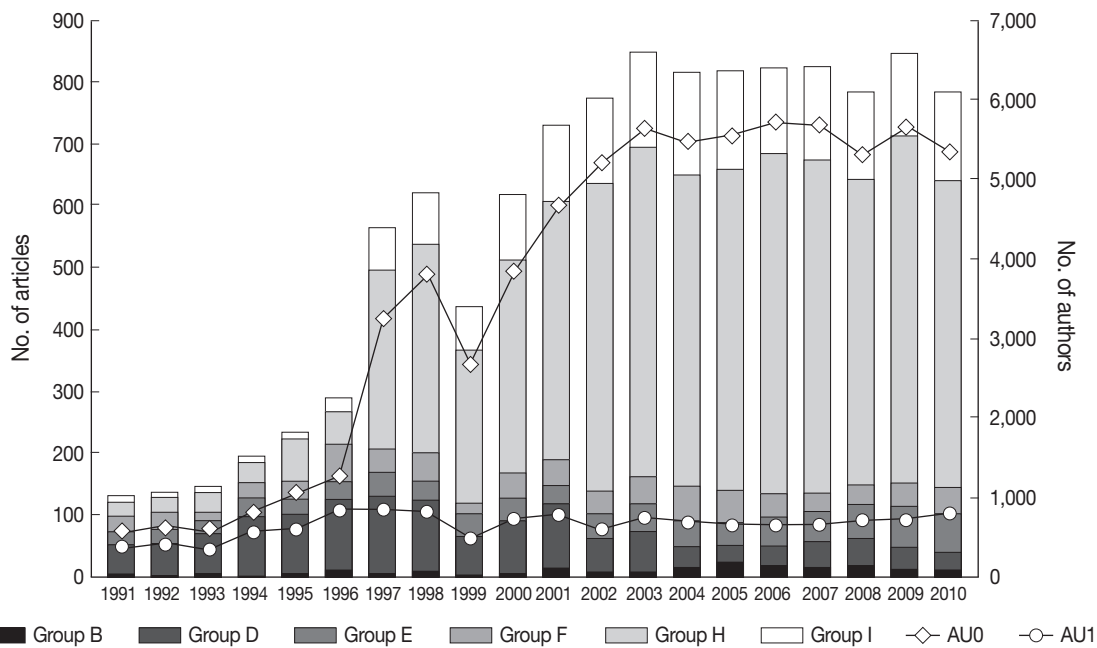
However, PPA1 has not shown a significant change since 1994; the number of PPA1 was 151, and this number of PPA1 was the same in 2009. The number of authors of PPA1 was 581 in 1994 and increased only 1.3 times up to 740 in 2009 (Table 1). The number of articles where the pathologist is the first author according to the journals researched is listed in Table 2. Among the PPA1, Korean J Pathol occupied 1,745 articles among 3,031 (57.6%), followed by J Korean Med Sci, which occupied 354 articles (11.6%) and Korean J Cytopathol, which occupied 337 articles (11.1%). The number of authors was mostly concordant with the number of articles, 58.3% with Korean J Pathol, followed by J Korean Med Sci (12.3%) and Korean J Cytopathol (10.9%).

The articles were grouped according to the co-authorship pattern in Table 1. Group A corresponds to the total number of articles where a pathologist was the first author (PPA1) while Group G is total number of articles that included pathologist participation (PPA0). Group B is PPA1 with a single author and Group C is PPA1 with multiple authors. Group C was further divided into four groups; Group D is PPA1 with multiple authors with-

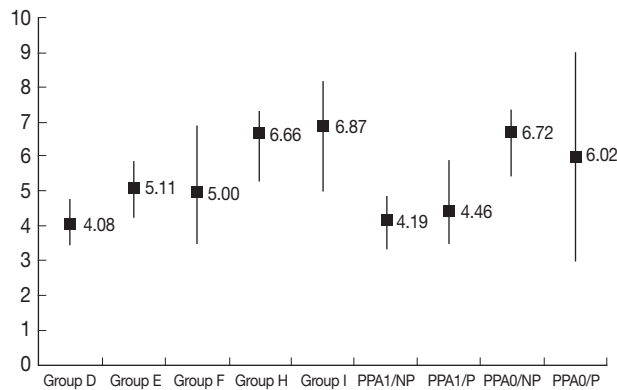
**Table 1.** The number of articles that pathologists participated in

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	
<b>Articles</b>																						
(A) 1st AU = Pathology	4	3	5	2	4	10	5	9	3	5	14	9	8	14	22	18	13	18	10	10	186	
(B) Author = 1	56	59	65	101	96	116	127	116	66	89	107	58	65	36	30	32	47	46	40	29	1,381	
(C) Author > 1	18	22	21	25	25	38	40	32	34	37	28	38	48	49	46	52	48	56	66	60	783	
(D) Intra pathology	19	22	12	23	32	51	36	42	19	38	41	35	43	50	42	36	27	29	35	49	681	
(E) Intra institution	25	24	33	36	67	54	287	337	245	343	418	497	529	500	519	547	538	496	563	491	6,549	
(F) Inter institution	9	8	11	8	11	18	71	85	69	105	123	138	157	165	158	140	151	139	132	142	1,840	
(G) 1st AU ≠ Pathology	131	138	147	195	235	287	566	621	436	617	731	775	850	814	817	825	824	784	846	781	11,420	
(H) Intra institution	74%	77%	70%	77%	67%	75%	37%	32%	28%	27%	26%	18%	19%	18%	17%	17%	16%	19%	18%	19%	27%	
(I) Inter institution																						
(J) Total	4	3	5	2	4	10	5	9	3	5	14	9	8	14	22	18	13	18	10	10	186	
(A) 1st AU = Pathology	218	228	224	365	356	441	492	448	247	379	425	235	266	149	141	152	224	208	159	130	5,487	
(B) Author = 1	83	94	90	123	123	180	194	158	159	176	147	190	280	269	255	291	263	329	371	327	4,102	
(C) Author > 1	79	93	42	91	135	225	167	218	84	183	196	175	199	260	254	219	169	170	200	336	3,495	
(D) Intra pathology	159	146	175	196	387	317	1,870	2,342	1,707	2,383	3,012	3,545	3,697	3,584	3,730	3,995	3,782	3,497	3,925	3,439	45,888	
(E) Intra institution	45	53	64	43	60	101	504	612	476	710	877	1,056	1,186	1,204	1,145	1,047	1,232	1,074	990	1,111	13,590	
(F) Inter institution	588	617	600	820	1,065	1,274	3,232	3,787	2,676	3,836	4,671	5,210	5,636	5,480	5,547	5,722	5,683	5,296	5,655	5,353	72,748	
(G) 1st AU ≠ Pathology																						
(H) Intra institution																						
(I) Inter institution																						
(J) Total																						

AU, author.



**Fig. 1.** The number of articles and authors by year. The increase of the total number of articles is mostly achieved by the increase of articles of Group H. The groups match the groups of Table 1. Group B: PPA1, single author; Group D: PPA1, multiple authors within a pathology department; Group E: PPA1, multiple authors from multiple departments within single institution; Group F: PPA1, multiple authors from multiple institutions; Group H: PPA0, multiple authors from single institution; Group I: PPA0, multiple authors from multiple institutions. AU0, number of authors of PPA0; AU1, number of authors of PPA1; PPA0, the number of articles that pathologists participated; PPA1, the number of articles that pathologists participated as first author.



**Fig. 2.** The number of authors per articles according to the author group ( $p < 0.001$ ). Group D: PPA1, multiple authors within a pathology department; Group E: PPA1, multiple authors, multiple departments, single institution; Group F: PPA1, multiple authors, multiple institutions; Group H: PPA0, multiple authors, single institution; Group I: PPA0, multiple authors, multiple institutions. NP, non-pathology journal; P, pathology journal (Korean J Pathol and Korean J Cytopathol); PPA0, the number of articles that pathologists participated; PPA1, the number of articles that pathologists participated as first author.

in a single pathology department; Group E is PPA1 with multiple authors of multiple departments within a single institution; Group F is PPA1 with multiple authors from multiple in-

stitutions. Group G is divided into two groups; Group H is PPA0 within a single institution; Group I is PPA0 with multiple institutions. The average number of authors per article among the group was significantly different ( $p < 0.001$ ). The number of authors per article was smallest in PPA1 within a single pathology department (4.076), while the largest number of authors is a PPA0 with multiple institutions (6.871) (Fig. 2).

For both the PPA1 or PPA0 articles, two main pathology journals (Korean J Pathol, Korean J Cytopathol) were compared to other journals. The average number of authors per article was not significantly different ( $p = 0.123$  and  $p = 0.095$ , respectively). In non-pathology articles, the number of authors per article was significantly different between PPA0 and PPA1 ( $p < 0.001$ ) (Fig. 2).

**Degree indices**

The centrality degree among the institutions was lowest in 2000 (2.6%) and highest in 1993 (10.7%); the average degree during the 1991-2010 was 4.16% (Table 3). The outdegree and indegree centrality are also shown. The centrality degree among the institutions showed a steady state in the most recent 10 years. The centrality degree among the authors varied from

Table 2. The journals that a pathologist is first author

Articles	Year												Total								
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002		2003	2004	2005	2006	2007	2008	2009	2010
Korean J Pathol	73	83	85	98	99	148	128	108	81	92	86	69	73	74	62	70	63	75	95	83	1,745
J Korean Med Sci	18	17	14	17	16	22	25	32	12	22	28	18	26	16	17	15	12	6	6	15	354
Korean J Cytopathol				30	31	32	26	30	10	17	20	14	17	18	15	22	25	30			337
Yonsei Med J	5	5	2	5	5	1	4	3	4	6	7	7	6	9	1	3	6	5	6	1	91
Korean J Hepatol						1				3	8	4	2	6	4	4	7	5	6	3	53
Cancer Res Treat										7	7	8	10	8	7	1		2	4	2	49
J Korean Cancer Assoc							9	12	4	3	1										29
Exp Mol Med									1	2		3	2	1	3	2	2		3	2	21
J Korean Gastric Cancer Assoc										4	4	1	8	1	3	1		1	1		20
Others	1	1	2	1	6	11	16	14	10	24	29	16	20	16	28	20	20	25	30	42	332
Total	97	106	103	151	157	215	208	199	122	169	190	140	164	149	140	138	135	149	151	148	3,031
Authors																					
Korean J Pathol	290	325	298	366	387	597	522	476	329	400	363	295	335	349	307	366	327	421	507	486	7,746
J Korean Med Sci	70	78	54	76	59	83	117	120	44	118	122	89	125	79	75	86	83	26	26	107	1,637
Korean J Cytopathol				121	140	142	104	106	45	69	80	55	79	94	62	99	112	139			1,447
Yonsei Med J	23	14	5	17	13	4	12	14	19	34	37	27	18	36	1	10	28	13	20	7	352
Korean J Hepatol										6	22	11	3	14	8	5	21	9	17	6	123
Cancer Res Treat						1					15	30	44	51	35	2		2	16	4	199
J Korean Cancer Assoc							44	60	10	10	4										128
Exp Mol Med									5	5		28	12	2	28	18	11		21	12	142
J Korean Gastric Cancer Assoc										25	10	59	78	9	28	8		5	1		145
Others	1	1	4	1	19	29	59	57	41	101	114	64	78	58	128	86	87	110	132	181	1,351
Total	384	418	361	581	618	856	858	833	493	743	782	609	753	692	672	680	669	725	740	803	13,270

0.21% in 2010 to 0.53% in 1993; the average centrality degree during 1991-2010 was 0.3%. The centrality degree was highest between 1992 and 1993 and then it decreased and showed a steady state since 1994 (Table 3).

The degree centrality analysis revealed a highest node of the year for the institution and for the author. During first 10 years, Seoul National University (SNU) was distinguished as highest degree institutions (7 times); however, over the last 10 years, the highest rank institutions were varied so that Ulsan held 3 times, followed by SNU, Sungkyunkwan University (SKKU), The Catholic University of Korea (CUK) 2 times and Yonsei 1 time, respectively (Table 3). The network diagrams of the institutions from 1991 to 2000 and from 2001 to 2010 are depicted in Fig. 3. For the first 10 years, SNU was both the highest ranker and key player; however, Ulsan replaced that position in the last 10 years.

The highest degree authors are listed in Table 3. Eighteen of twenty of the highest rankers were generating networks with high outdegree. Only two authors, Kim, Yong Il and Chi, Je Geun generated networks with high indegree which suggest these authors were corresponding authors. Noticeably, Yoo, Jinyoung was placed as the highest ranker on three. For the authors' network, node betweenness and closeness centrality were measured (Table 4). Notably, Chi, Je Geun and Lee, Kyo Young were highest four and three times respectively in closeness centrality.

The network centrality degree and the number of articles that showed a significant correlation (Table 5). In particular, PPA1 was significantly negatively correlated with degree of centrality of institute and authors ( $p < 0.01$ ). However, node centrality showed a positive correlation ( $p < 0.01$ ).

### KeyPlayer analysis

A KeyPlayer analysis was performed by a distance weighted fragmentation criterion me-

**Table 3.** Centrality indices of the institutions and authors according to the year

Year	Network centrality						Node centrality									
	Institution			Author			Institution			Author						
	Out-degree	Indegree	Degree (%)	Out-degree	Indegree	Degree (%)	Highest node	Outdegree	Indegree	Share (%)	Highest node	Outdegree	Indegree	Degree	Share (%)	
1991	7.28	2.22	6.04	1.29	1.18	0.39	SNU	7.50	2.50	8.75	18.40	Kang, Gyeong Hoon	1.43	0.00	1.43	2.30
1992	4.87	1.7	6.48	1.77	1.77	0.50	SNU	5.00	1.25	6.25	20.80	Kim, Yong Il	0.83	1.94	2.35	2.80
1993	1.20	1.63	10.70	1.09	1.80	0.53	SNU	1.25	1.25	2.50	25.00	Chi, Je Geun	0.08	1.89	1.89	4.80
1994	2.32	3.59	5.12	1.64	1.19	0.28	SNU	1.25	3.75	5.00	15.40	Chung, Jae Gul	1.80	0.11	1.91	2.00
1995	1.50	3.61	4.45	1.01	0.72	0.28	SNU	0.83	3.75	4.58	15.30	Go, Jai Hyang	1.04	0.15	1.18	1.80
1996	3.06	4.75	3.94	1.09	0.94	0.25	SNU	2.92	5.00	6.25	14.40	Kim, Kyu Rae	1.20	0.38	1.42	1.50
1997	4.10	3.47	3.74	0.76	0.40	0.22	SNU	1.88	3.75	5.00	10.30	Palk, Seung Sam	0.80	0.06	0.80	2.10
1998	2.31	2.31	4.36	0.72	0.46	0.22	SKKU	2.19	2.50	4.06	12.00	Lee, Won Mi	0.78	0.10	0.89	1.40
1999	1.73	1.09	3.80	1.64	0.74	0.23	Inje	1.88	0.63	2.50	9.50	Yang, Seok Woo	1.81	0.00	1.81	1.60
2000	1.88	1.88	2.60	0.85	0.62	0.22	Ulsan	0.83	2.08	2.50	7.30	Chun, Yi Kyeong	0.93	0.06	0.93	1.40
2001	2.78	2.78	2.83	0.83	0.52	0.24	SKKU	1.88	3.13	5.00	8.50	Lee, Min Cheol	0.90	0.16	1.06	1.70
2002	5.33	2.80	4.50	1.26	0.80	0.23	Ulsan	5.63	3.13	8.13	15.10	Jung, Kyeong Cheon	1.27	0.23	1.50	1.40
2003	1.69	2.32	2.99	1.31	0.35	0.33	SKKU	0.31	2.50	2.81	8.50	Kim, Na Rae	1.37	0.09	1.41	2.70
2004	3.43	3.43	3.05	1.61	0.35	0.36	Ulsan	2.50	2.50	5.00	9.10	Yoo, Jinyoung	1.66	0.00	1.66	3.40
2005	3.89	1.78	2.86	1.14	0.35	0.38	CUK	4.17	0.42	4.17	8.20	Yoo, Jinyoung	1.19	0.00	1.19	2.90
2006	6.49	3.96	3.87	0.95	0.50	0.24	Yonsei	5.00	3.13	6.88	9.80	Yoo, Changyoung	1.04	0.00	1.04	1.30
2007	2.88	3.51	3.45	1.28	1.11	0.30	SNU	3.13	1.88	5.00	10.80	Yoo, Jinyoung	1.30	0.57	1.54	1.90
2008	2.85	2.85	3.68	1.25	0.48	0.30	Ulsan	3.13	3.13	6.25	12.80	Chang, Sun Hee	1.31	0.33	1.37	2.30
2009	5.75	4.48	3.44	1.14	0.67	0.22	SNU	6.25	2.50	8.75	9.70	Choi, Yoo Duk	1.21	0.07	1.21	1.60
2010	5.20	5.20	2.75	1.28	0.78	0.21	CUK	5.63	1.88	6.25	8.10	Park, Bong Hee	1.40	0.10	1.50	1.30

SNU, Seoul National University; SKKU, Sungkyunkwan University; CUK, Catholic University of Korea.

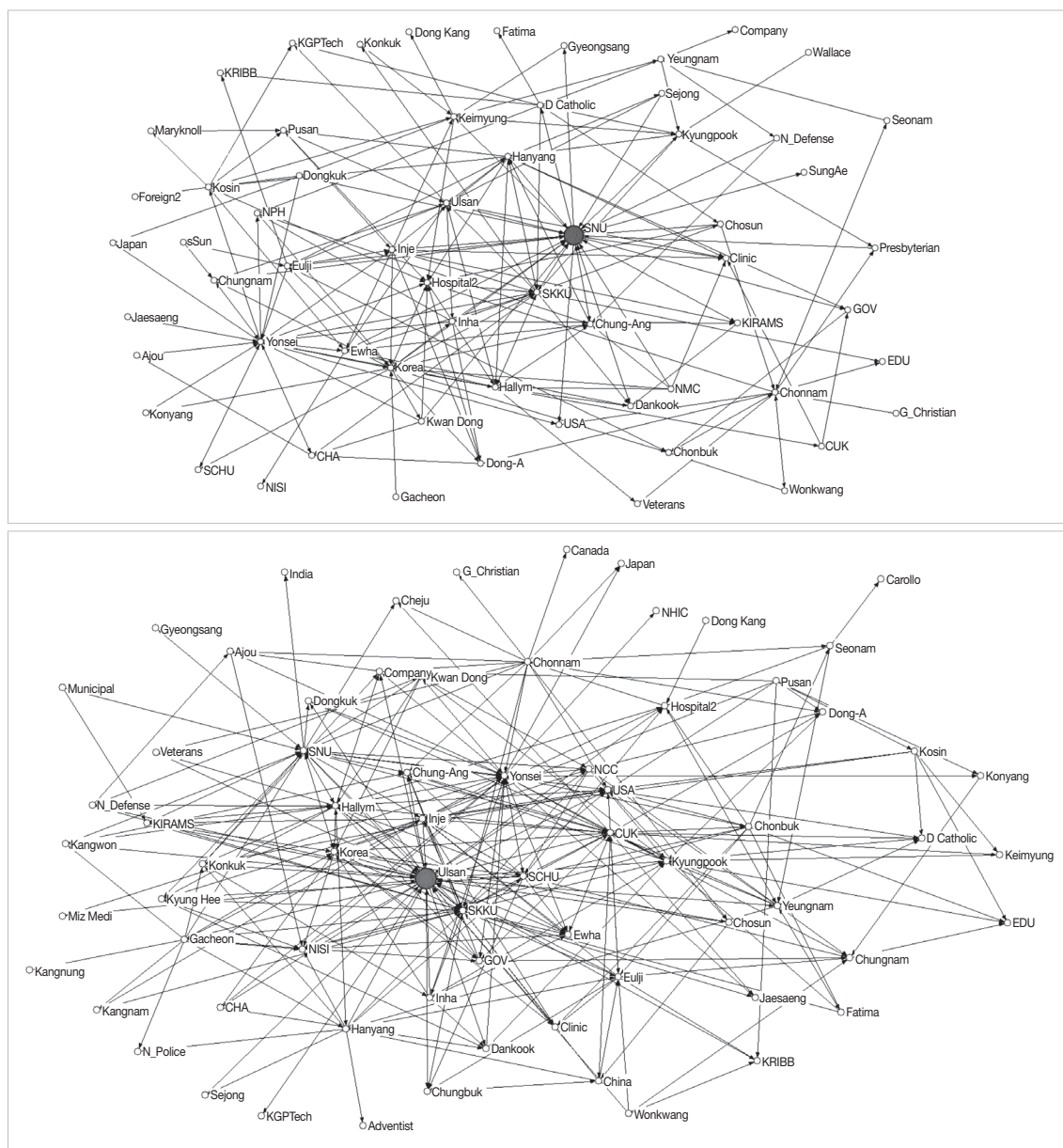
thod used set to a group size of 1 or 3 with up to 5,000 iterations to select key players for each year. The group size was set differently because the size of the network was much bigger for the authors. The key player of institution showed that in the early 1990's, SNU was a unique key player. However after 2001, Ulsan was a major key player (Table 6, Fig. 3). The authors, Chi, Je Geun were selected 5 times, whereas Kim, Na Rae were selected 3 times (Table 6). For the first 10 years, Chi, Je Geun was a distinguished key player, and for the last 10 years Kim, Na Rae was the key player.

### Sociogram

Fig. 4 shows the network of authors in 2010 which denotes the nodes of the highest degree, highest betweenness, highest closeness centrality, and key players.

## DISCUSSION

The co-authorship networks analysis can measure network status among the society and dynamically visualize the co-authorship patterns over selected time periods. Also, it can identify and visualize the most prominent actors over time and their ego-networks, as well as capture the nature and characteristic of the research topics over time through visualizing the network of keywords found in the published papers. Given that we have established a social network graph, we can describe its properties on two levels; one for the network as a whole, and one for a node that was composed with the network. The term 'centralization' is used to refer to the particular properties of the network structure as a whole and 'degree centrality' is used simultaneously. Practically, the degree of centrality of a network denotes 'how the network is well connected.' It is an index of exposure to what is flowing through the net-



**Fig. 3.** The network sociogram among the institutions. Upper: from 1991 to 2000, SNU was both a highest ranker and key player. Lower: from 2001 to 2010, the highest ranker and key player was changed to Ulsan. SNU, Seoul National University; SKKU, Sungkyunkwan University; CUK, The Catholic University of Korea; SCHU, Soonchunhyang University; KIRAMS, Korea Institute of Radiological & Medical Sciences; NCC, National Cancer Center; NHIC, National Health Insurance Cooperation Hospital; NISI, National Institute of Scientific Investigation.

work and can be interpreted as opportunity to influence and be influenced directly. Meanwhile, the centrality of a node (institution or author) is its degree and does not represent structural characteristics of a network. The value of degree may denote ‘point (node) centrality’ or ‘graph (network) centrality.’ These sociologic terms may cause confusion to the researchers in a non-sociology field. Thus in the current article, we used ‘network centrality’ and ‘node centrality’ to denote centrality de-

gree of the network and node (institution or author), respectively.

In a previous report, the network centrality degree of the network, which confined us to the scientific citation index expanded (SCIE) articles of the “Pathology” field published by Korean Medical Schools, was 36.2%, and adjusted to 2.19% after normalization.<sup>2</sup> The degree is relatively lower than other medical research fields. In the current study, the degree of network cen-

**Table 4.** Closeness centrality and betweenness centrality of the authors

Year	Closeness			Betweenness	
	Highest node	In closeness (%)	Out closeness (%)	Highest node	Betweenness (%)
1991	Kim, Yong Il	47.6	43.7	Park, Chan Il	20.9
1992	Choi, In Joon	46.7	41.3	Kim, Chul Woo	43.6
1993	Chung, Hai Won	51.2	46.9	Myong, Na Hye	9.5
1994	Chi, Je Geun	36.0	33.7	Jung, Woo Hee	10.1
1995	Chi, Je Geun	31.2	29.5	Jung, Woo Hee	6.1
1996	Chi, Je Geun	23.8	22.4	Kim, Yong Il	22.8
1997	Chi, Je Geun	21.5	20.6	Kim, Sung Sook	2.7
1998	Han, Jounggho	21.4	20.8	Kim, Duck Hwan	2.1
1999	Won, Nam Hee	31.0	30.0	Cho, Hyun Deuk	6.6
2000	Ro, Jae Y	23.8	23.1	Jung, Jong Jae	3.6
2001	Kim, In Sun	21.7	21.1	Noh, Tae Woong	3.1
2002	Khang, Shin Kwang	23.6	23.0	Kim, Kyu Rae	4.2
2003	Park, Moon Hyang	23.4	22.7	Kim, Na Rae	7.5
2004	Suh, Yeon Lim	23.0	22.4	Jeong, Hyeon Joo	2.1
2005	Park, Moon Hyang	24.2	23.7	Oh, Young Ha	3.9
2006	Lee, Kyo Young	22.5	22.1	Lee, Hee Eun	2.2
2007	Lee, Kyo Young	24.9	24.3	Park, Gyeongsin	3.0
2008	Lee, Kyo Young	22.1	21.8	Chang, Sun Hee	1.3
2009	Han, Jounggho	20.7	20.2	Jung, Eun Sun	2.1
2010	Ha, Hongil	20.2	19.9	Choi, Yong Soo	1.8

**Table 5.** Centrality indices and relationship with the number of articles

	Degree (%)	PPA0		PPA1	
		Pearson	p-value	Pearson	p-value
Network centrality					
Institute					
Outdegree	3.53 (1.20-7.28)	0.142	0.55	-0.276	0.238
Indegree	2.97 (1.09-5.20)	0.249	0.29	0.402	0.079
Degree		-0.707**	0.00	-0.520*	0.019
Authors					
Outdegree	1.20 (0.72-1.77)	-0.232	0.325	-0.599**	0.005
Indegree	0.79 (0.35-1.80)	-0.733**	0.00	-0.576**	0.008
Degree		-0.466*	0.038	-0.638**	0.002
Node centrality					
Institute					
Outdegree	0.45 (0-7.50)	0.518**	0.000	0.595**	0.000
Indegree	0.39 (0-5.00)	0.506**	0.000	0.461**	0.000
Authors					
Outdegree	0.091 (0-1.936)	N/A		0.814**	0.000
Indegree	0.092 (0-1.936)	N/A		-0.162**	0.000

\*Significant at 0.05; \*\*Significant at 0.01.

PPA0, the number of articles that pathologists participated; PPA1, the number of articles that pathologists participated as first author.

tralization among all institutions in this study over a 20-year period was 1.77% (data not shown in Table). This finding is slightly lower than the previous report mentioned above because the current research included domestic articles, which meant that more authors and institutions were enrolled for the network analysis. The network centrality degree among the in-

stitutions after 1996 did not show much of a difference. Like the network centrality degree of institutions, the degree of centrality in authors did not change since 1994. This indicates that the communications among the pathology institutions or among the authors are not improving. The possible reason of this phenomenon is that the number of articles and the number of authors of PPA1 did not increase during the period (Fig. 1).

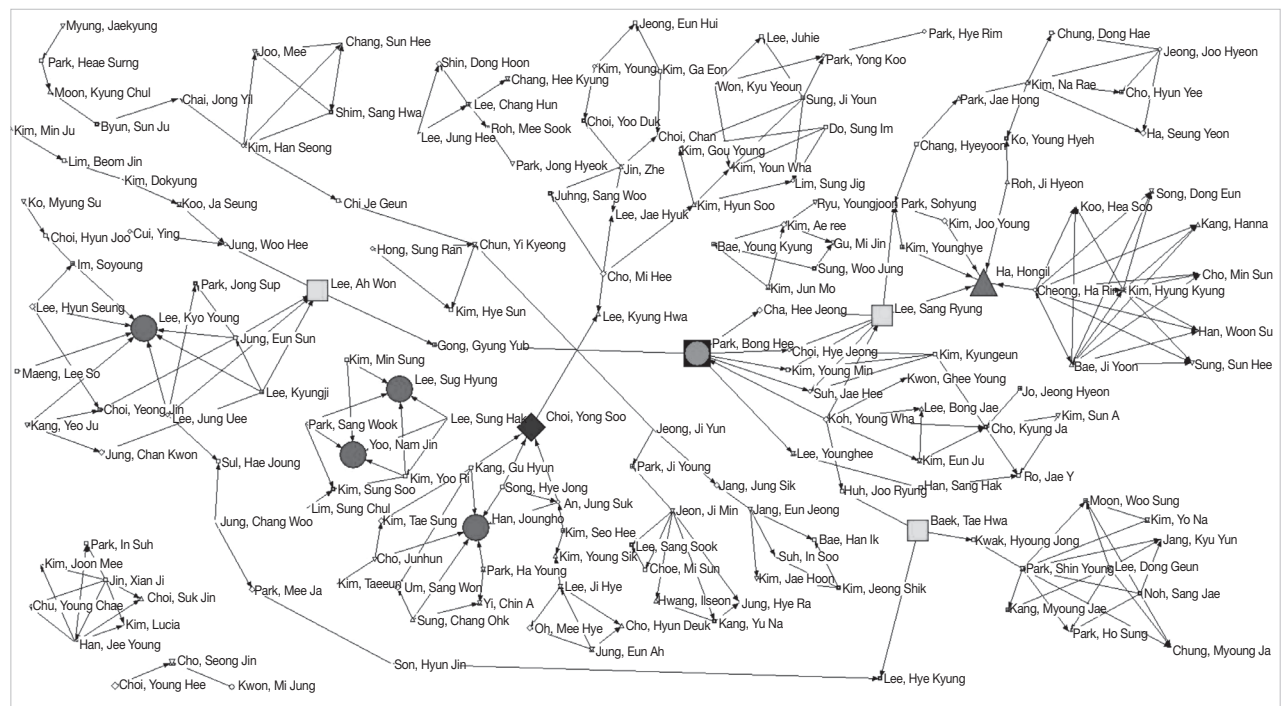
The highest ranker of institute network showed remarkable changes during the period. From 1991 to 1997, SNU was an exclusive highest ranker. After 1997, several institutions emerged as major nodes of the network. Since 1998, Ulsan was highest 4 times, SKKU was highest 3 times and CUK was highest twice, when compared with the SNU 2 times. In 1999, Inje was a highest ranker but this year will require a cautious interpretation that the total number of articles was abruptly reduced from 208 in 1997 to 122 in 1999 because of the economic crisis of Korea in 1998 and that the network was temporarily waved. From 1991 to 2000, SNU occupied 10.35% of the network, followed by Yonsei 5.8%, and SKKU 5.5%. In this period, Ulsan occupied only 3.6% of the network. However, from 2001 to 2010, Ulsan was highest with 7.1% occupancy, followed by SKKU 6.5%, SNU 6.1%, and Yonsei 5.1%. Another remarkable change is that the CUK which occupied only 0.9% in the first 10 years, showed a dramatic increase up to 3.8% in the last 10 years. This change was possible with the appearance of Yoo, Jinyoung, who had the highest degree in 2004, 2005, and 2007.



**Table 6.** The result of KeyPlayer analysis

Year	Institution	Authors
1991	SNU	Kim, Yong Il
1992	SNU	Kim, Kyu Rae
1993	SNU	Chi, Je Geun
1994	SNU	Chi, Je Geun
1995	SNU	Chi, Je Geun
1996	SNU	Kim, Kyu Rae
1997	Hanyang	Chi, Je Geun
1998	SKKU	Suh, Yeon Lim
1999	Yonsei	Kim, Hee Jung
2000	Ulsan	Chun, Yi Kyeong
2001	Ulsan	Hong, Eun Kyung
2002	Ulsan	Kim, Na Rae
2003	SNU	Kim, Na Rae
2004	Ulsan	Kim, Na Rae
2005	CUK	Kim, Dong Hoon
2006	Yonsei	Yoo, Changyoung
2007	Chonnam	Kang, Jun
2008	Ulsan	Lee, Kyo Young
2009	CUK	Jung, Eun Sun
2010	SKKU	Lee, Ah Won

SNU, Seoul National University; SKKU, Sungkyunkwan University; CUK, The Catholic University of Korea.



**Fig. 4.** The network sociogram of authors in 2010. Isolated and pendulous nodes were removed for the convenience of the viewer. Circle in box, highest centrality degree; Circle, 4 or more articles; Square, key players; Diamond, highest betweenness; Triangle, highest closeness.

Among the highest rankers of the years are listed in Table 5, two authors, Kim, Yong Il and Chi, Je Geun had high indegree and low outdegree indices which is typical pattern of ‘corresponding author.’

Closeness centrality denotes ‘how far from all others and how long information takes to arrive.’ It is an inverse measure of centrality and is an index of expected time until the arrival of a given node of whatever is flowing through the network. A simple

explanation of this is 'central player hears things first.' High node centrality means 'popularity' and high node closeness means a close friend of a 'popular person.' Two authors in Table 6, Chi, Je Geun and Lee, Kyo Young were distinguished with high closeness. It is quite reasonable to suppose that those two authors were working with highest centrality authors. For example Lee, Kyo Young hears things first from Yoo, Jinyoung. And Chi, Je Geun had highest indegree for several times which means many first authors are working with him.

The betweenness centrality denotes 'how often a node lies along the shortest path between two other nodes' and it is an index of potential for gatekeeping, brokering, and controlling the flow. Thus the highest betweenness author is supposed to be an author whose position acts as a bridge between two unfriendly or unfamiliar groups. The highest betweenness author does not need to be an author with many articles. Critical to betweenness is 'the position' of the node. For example, the highest betweenness degree authors is Choi, Yong Soo, who have only one article with 12 authors in 2010, because his position is located between two larger groups. Two similar positioning nodes Park, Ji Young and Gong, Gyoung Yub are also found. But Park, Ji Young was located between smaller groups than Choi's and had Gong, Gyoung Yub had bypass through Huh, Joo Ryung (Fig. 4).

The centrality indices and the number of articles show a significant relationship. Degree centralities of institute and authors showed a significant negative relationship with PPA0 and PPA1. As the number of articles increased, the degree of centralization was reduced, which means as the number of articles increased, more communications among the institutions and among the authors are occurring. However node centralities showed a positive correlation with the PPA0 and PPA1 except for the indegree of the author's network. The positive correlation suggests that as the number of articles increased, the oligopolies by several authors/institutions worsened.

However, it must be understood that the degree of network does not necessarily mean its academic quality. The current research used only domestic journals from the KoreaMed database

so that the articles published by international journals, which have higher impact factors and citation numbers than domestic journals, were not included. The network associated with international pathologists also should be concerned by further research. Thus, the degree only means 'the degree of having communication' among the Korean Pathologists. Nevertheless, the authors with the highest degree listed in Table 5 are now regarded as excellent researchers by the pathologists' society according to our experience.

In the research, we tried to visualize the pattern of co-authorship and the network among the pathologist society. The research clearly revealed that the network is a 'typical small society' governed by only a few institutions and author groups. To make the pathologists' society strengthened to survival and growth, as we mentioned earlier, a strategic plan to uncover the cloud of oligopoly over the society is needed.

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