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PATENT BASED TECHNOLOGICAL-LEVEL EVALUATION OF DENTAL IMPLANTS INDUSTRY

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Abstract. *Strategic R&D to acquire technology is very important not only for companies but also for countries. For successful R&D, companies need to understand technology trends as well as their strength and weakness. In this paper, technology trends in dental implants industry and technological-level of major 11 countries are studied using patent data. The trends of patent applications are investigated for 3 sectors of implant technology: fixture, abutment and surface treatment. The U.S. is by far the strongest in all sectors, given the number of patent applications. Though Korea and Japan recently have the rapid growth in the number of patent applications in surface treatment sector, their technological-levels are still the lowest compared to other countries. Sweden, the U.S., and Canada are identified as the leading countries with influential implant technology and strong market presence. By referring the result of this study, it is expected that each country will be able to develop its own R&D strategy to acquire market dominance through wise technology investment.*

Keywords: Dental implant, Patent analysis, Technological-level evaluation, Revealed technological advantage, Technology strength

1. **Introduction.** Dental implants are artificial teeth that help people chew food in place of their natural teeth that are no longer available. Dental implants commercialized in Europe and the U.S. in the 1990s have been used worldwide since the 2000s with the development of related technologies [1]. It is excepted that the global implants market will grow from $4.5 billion in 2016 to $6.3 billion in 2020 [2]. Conventional researches on dental implants are largely focused on material and quality issues, and they lack analysis on R&D trends and market directions of major countries that lead technologies. In this study, the structure of the dental implants market is investigated via quantitative analysis of Technological-Level (TL) of each country to understand the future direction of technology. It is based on the national patent data in the technology sectors related to dental implants over last 20 years. Quantitative results such as the number and trend of patent applications, the proportion of patent applications in each country, and the patent application trend for each technology sector are presented through the classification of patent data by country. Countries with strong market dominance are also analyzed via the size of patent families, and finally, the TL of each country is assessed by identifying CPP (Cites Per Patent), PII (Patent Impact Index), and TS (Technology Strength) using patent data registered in the U.S..

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The remainder of this paper is organized as follows. Following Section 2 explains several important patent indicators and background studies related to this study. Section 3 describes the data and basic analysis result of this study, and Section 4 illustrates the TL analysis results. Finally, in Section 5, the conclusions of this study are summarized.

2. **Patent Indicators and Related Works.** Technological-Level Evaluation (TLE) is mainly done through qualitative and quantitative study. Qualitative analysis is often performed by expert judgment, such as Delphi survey, brainstorming, and interviewing, while quantitative analysis is performed by studying relevant patents or dissertation data. Although the process of qualitative analysis is relatively easy, there is a disadvantage that it can be biased toward the subjective judgments of the experts. Quantitative analysis, on the other hand, can be objective because it uses data generated over a long period of time that meet certain criteria for study. This section introduces some patent indicators used for quantitative analysis in this study and outlines several related studies that utilize those patent indicators.

2.1. **Patent indicators.** Patent indicators used in this study can be categorized into 2 groups. The first group is used to capture the patent trends of implant-related technology, and the second group is used to assess TL by the importance or influence of each country's implant technology through patent citation data. Table 1 summarizes the indicators for these 2 groups along with their definition.

Table 1. The definition of patent indicator used in this study

	Patent Indicators	Definition
Trend Indicators	Number of applications	Number of applications by specific agent
	Application distribution by patent offices	Patent application distribution of countries by patent offices
	Application distribution by technology	Patent application distribution of countries by technology
	Revealed Technological Advantage (RTA)	Relative level of specific agent to specific technology $RTA = \frac{Rate\ of\ specific\ technology\ to\ specific\ agent's\ patents}{Rate\ of\ specific\ technology\ for\ all\ patents}$
	Number of patent families	Number of patent applications to each patent office by the same invention
	Patent Family Size (PFS)	Value of average patent family of specific agent divided by all average patent family $PFS = \frac{Average\ patent\ family\ of\ specific\ agent}{All\ average\ patent\ family}$
TLE Indicators	Cites Per Patent (CPP)	Ratio of the specific agent of patents cited by other patents
	Patent Impact Index (PII)	Relative proportion of the specific agent's CPP for average CPP $PII = \frac{Specific\ agent's\ CPP}{Average\ CPP}$
	Technology Strength (TS)	PII multiplied by the number of patents $TS = PII \times The\ number\ of\ patents$

The number of applications helps us to identify technology trends related to the R&D of dental implants in a country by adding up all related patent applications in that country. The higher the number of applications, the more R&D activities for that technology [3]. The application distribution by patent offices is based on the number of applications for 5 major patent offices which are Korea, the U.S., Europe, Japan, and PCT (Patent Cooperation Treaty). It can explain the level of R&D activities of a country from the market perspectives by indicating how much portion of the implant-related applications

of a country comes from the other countries. A country usually has the largest number of applications in domestic patent office. If the portion of other country's patent applications is relative high in domestic region, then it can be judged that other country has high level of R&D activity, and shows strong interest in domestic market [4]. The application distribution by technology indicates the country-wise percentage of patent applications in each technology sector of dental implants. The level of R&D activity of a country in a particular technology sector can be explained through this indicator [3]. RTA is one of the most commonly used patent indicators for TLE, indicating which country's R&D activities are focused on a specific technology sector compared to the other countries' average R&D activities on that sector. RTA value 1.0 means that about the average level of R&D activity has been performed in the relevant technology sector of a country across all countries' R&D activities in that sector. An RTA value less than 1.0 indicates that the activity in that technology sector is relatively low in the country, and a value greater than 1.0 indicates that the R&D activity is high. Patent families are a collection of patents filed in various patent offices for the protection of specific patents. By capturing the number of patent families, one can understand the extent to which the rights of a patent are covered. A patent with a large number of patent families can be considered of a technology with value and importance. PFS is the average number of patent families in a given country divided by the average of all patent families in all countries. This represents the share of patents held by a particular country on technologies with market dominance and technical value [5].

The CPP is an indicator of how much the patent has been quoted in other patents. The larger the value of CPP, the more likely it is that the applicant of that patent has a lot of core technologies in that field. The PII is the quotient of a specific country's CPP and the average CPP. This shows how high the TL and the influence of a particular country are compared to the average of all countries in that field. PII value 1.0 indicates that the TL and the influence of a country are about the average level of all countries. A PII value greater than 1.0 indicates that the country's qualitative advantage on the technology, and a value less than 1.0 indicates qualitative disadvantage. The TS is an index that provides information on technological impacts considering both the qualitative and quantitative aspects of patents owned by a specific entity while supplementing PII that emphasizes only the qualitative aspects of a technology. The larger the TS value, the more likely it is that the patent holder has a relatively high technical impact both qualitatively and quantitatively [6].

2.2. **Related works.** Qualitative and quantitative TLEs have been applied in many areas. However, for TLEs that are directly related to R&D of specific technology, quantitative approach which provides advantages such as simple judgment and objectivity has been preferred over qualitative one that takes more time for result aggregation and incurs relatively high cost [7]. As patent data increases rapidly, quantitative approaches become widely applied for identifying trends, technology analysis, and strategy development [8]. Gao et al. established a model to understand the current state of technology and to forecast its trends from the technology life cycle using the number of patent applications and patent indicators. They applied the model to establishing R&D strategy for specific technologies [9]. Geum et al. proposed a model that measures the strength and scope of technology convergence between BT and IT through patent-index analysis while focusing on recent converging trends of technology innovation [10]. Narin et al. found that the citation index and the number of patents such as CPP and PII could be effective indicators for corporate technical capabilities while using patent information and citation data from the 17 pharmaceutical companies in the U.S. [11]. Lee et al. also proposed a quantitative model for predicting trends of similar technologies by analyzing patent indicators such as CPP and PII from patent data [12]. Chang et al. classified patent groups by using core

keywords in the patent data on dental implants. By analyzing patent groups, they created a patent map for implants technology. After analyzing the patent map to determine the quality of patent map, they were able to identify R&D strategies of dental implants technology [13]. Altuntas et al. suggested a method to forecast technology success based on patent data. They demonstrated their method using patents related to liquid crystal display and flash memory technologies [14]. Choi et al. proposed a patent analysis approach for managing sustainable technology. To apply their approach to actual problem, patents related to telematics technology were collected and analyzed for R&D strategy [15]. Kim and Bae also proposed an approach to predict technology using patent data. It was predicted by collecting patent documents and conducting application and citation analysis. They applied their method to wellness care industry [16].

3. **Research Data and Basic Analysis.** Patents related to artificial dental implants filed or registered between 1994 and 2013 were collected and analyzed. For 5 patent offices (South Korea, the U.S., Europe, Japan, and PCT), a patent search was conducted over 3 implant technology sectors (fixture, abutment, and surface treatment). Out of 16,759 patents searched, only 2,873 patents were finally used by excluding irrelevant patents. Table 2 shows search keywords and the number of patents in each technology sector. More than half of patents are from the fixture sector while recently declining in numbers, and the other two sectors are steadily increasing in their numbers. Out of 45 countries found at the patent search, the top 11 countries with 2,635 patents describe 92% of all applications.

The number of patent applications and relative ratios for the top 11 countries are shown in the left of Figure 1. The U.S. is the top most country accounting for 35.9%

Table 2. Search keywords and the number of patents found

Technology Sector	**Search Keywords** (including 'Dental Implant')	**Number of Patents** (for application years)				
		1994 ∼1998	**1999 ∼2003**	**2004 ∼2008**	**2009 ∼2013**	**Total (%)**
Fixture	Fixture, Bone Resorption, Stress Distribution, etc.	249	337	563	474	1,623 (56.5)
Abutment	Abutment, Connection, Interface, etc.	144	161	205	290	800 (27.8)
Surface Treatment	Surface Treatment, Blasting, Etching, Coating, Oxidation, Layer, etc.	38	91	151	170	450 (15.7)

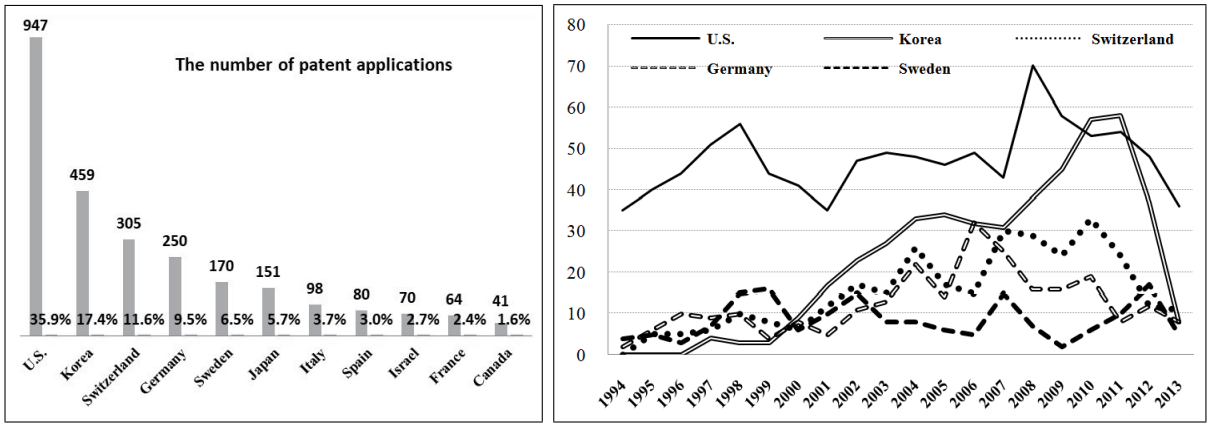

Figure 1. The number of patent applications and the trends of top 5 countries

of all applications, followed by South Korea with 17.4%. Annual application trends for each country during the study period are plotted in the right of Figure 1. The U.S. has steadily filed many applications throughout this period. The number of patents has sharply increased in Korea compared to other countries since 2000. Before then, implants in Korean market were highly dependent on imports. With the coverage expanse of national health insurance to dental implants and the policy support to related companies, the production of domestic implants has rapidly replaced imports together with the growth of related patents since 2000.

Many implants companies apply for international patents to tackle the overseas market, let alone their own domestic market. Table 3 represents the application distribution of 5 patent offices from top 11 countries. More than 60% of the patents are filed to the U.S. (41%) and EU (20%) out of 5 patent offices, which is reasonable considering their large market volume. Korea has the next largest number of applications accounting for 17% of the total. This is a notable result showing Korean companies' active R&Ds considering its relatively small market size. The bold figures in Table 3 show the patent offices to where each country filed the largest number of patents. Countries typically submit the most to their local patent office or to the U.S. Korea also filed the most to its local patent office, but domestic application of 76.5% (351 out of 459 applications) looks particularly high compared to the others. Although Korea has the second largest number of applications next to the U.S., high domestic patent ratio shows that Korean companies are not active in entering overseas market.

Table 3. Application distribution of 5 patent offices

Appl. / PO	U.S.	KR	SZ	GR	SD	JP	IT	SP	IS	FR	CA	Total (%)
U.S.	**616**	36	**111**	83	**61**	34	33	**27**	**37**	18	**24**	1,080 (41)
EU	119	15	109	**95**	60	25	**42**	25	14	20	6	530 (20)
PCT	145	45	42	46	26	4	20	21	17	**24**	10	400 (15)
KOREA	27	**351**	22	11	11	8	0	4	1	2	0	437 (17)
JAPAN	40	12	21	15	12	**80**	3	3	1	0	1	188 (7)
Total	947	459	305	250	170	151	98	80	70	64	41	2,635 (100)

*KR: Korea, SZ: Switzerland, GR: Germany, SD: Sweden, JP: Japan, IT: Italy, SP: Spain, IS: Israel, FR: France, CA: Canada

Table 4 shows the distribution of patent applications between countries in each implant technology sector along with corresponding RTA values. Bold numbers in the table show the top 2 countries in each column. In all technology sectors, the United States and Korea are the top 2 countries with the most patent applications. Since more than half of the applications are filed at the fixture sector, the application distribution of country total is very similar to that of fixture sector. Unlike the fixture and abutment sector which show a significant gap in the applications between the U.S. and Korea, the difference is relatively close in the surface treatment sector. This implies that Korea is more active in surface treatment compared to the other sectors. This focused R&D activity of Korea can also be confirmed by the RTA value. Unlike the U.S. showing about the average level of specialization by RTA values close to 1.0, Korea has high RTA value (1.74) in surface treatment. Japan has the second highest RTA value of 1.44 in surface treatment, which implies that Korea and Japan are focusing their R&D activities onto this technology sector more than the others.

Since the U.S. has the largest implants market and the world's leading companies are competing in the U.S. to secure their market, the U.S. patent information has significant implications for analysis. To analyze patent families, authors have utilized the U.S.

TABLE 4. Application distribution and RTA of each country by technology sectors

Sector / PO	Fixture		Abutment		Surface Treatment		Country Total	
	Applications (%)	RTA	Applications (%)	RTA	Applications (%)	RTA	Applications (%)	Average RTA
U.S.	**517 (34.5)**	0.97	**291 (40.6)**	**1.10**	**139 (33.0)**	0.94	**947 (35.9)**	1.00
KR	**219 (14.6)**	0.84	**115 (16.1)**	0.90	**125 (29.7)**	**1.74**	**459 (17.4)**	**1.16**
SZ	181 (12.1)	1.05	83 (11.6)	0.98	41 (9.7)	0.86	305 (11.6)	0.96
GR	160 (10.7)	1.13	54 (7.5)	0.78	36 (8.6)	0.92	250 (9.5)	0.94
SD	105 (7.0)	1.09	53 (7.4)	**1.12**	12 (2.9)	0.45	170 (6.5)	0.89
JP	81 (5.4)	0.95	36 (5.0)	0.86	34 (8.1)	**1.44**	151 (5.7)	**1.08**
IT	63 (4.2)	1.14	26 (3.6)	0.95	9 (2.1)	0.59	98 (3.7)	0.89
SP	47 (3.1)	1.04	19 (2.7)	0.85	14 (3.3)	1.12	80 (3.0)	1.00
IS	51 (3.4)	**1.29**	18 (2.5)	0.92	1 (0.2)	0.09	70 (2.7)	0.77
FR	47 (3.1)	**1.30**	12 (1.7)	0.67	5 (1.2)	0.50	64 (2.4)	0.82
CA	27 (1.8)	1.17	9 (1.3)	0.79	5 (1.2)	0.74	41 (1.6)	0.90
Total	1498 (100)	11.97	716 (100)	9.92	421 (100)	9.38	2635 (100)	10.42

*KR: Korea, SZ: Switzerland, GR: Germany, SD: Sweden, JP: Japan, IT: Italy, SP: Spain, IS: Israel, FR: France, CA: Canada

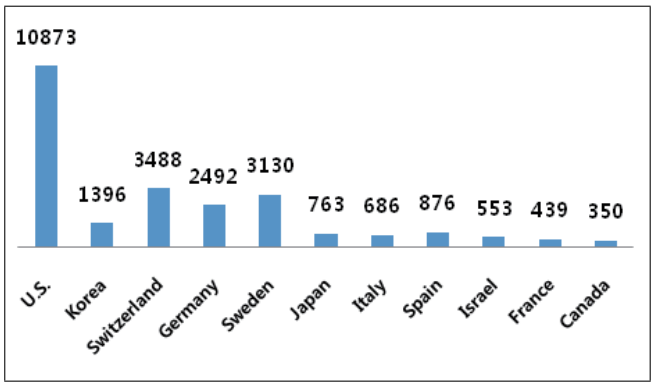

FIGURE 2. The number of patent families

patent office's data between 1994 and 2018. The number of patent families in Figure 2 shows the U.S. dominance in the world market. After the U.S., European countries such as Switzerland, Sweden, and Germany follow. Korea comes at the 5th position in the number of patent families, which contrasts its 2nd position in the number of patent applications. This implies that Korea's global market penetration is low and they concentrate in domestic market. The PFS value in Figure 3 gives similar result. Korea has the lowest PFS value (0.31) among 11 countries. Sweden has the highest PFS value (2.10), which explains that their relative number of patent families for patent applications are higher than the average rate of all countries despite their small number of patent applications.

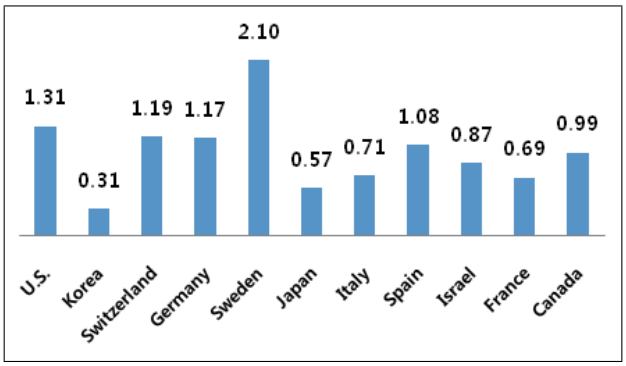

FIGURE 3. PFS value by country

4. **Result of TLE by Country.** To obtain TLE indicators of this study, citation information between patents is crucial. Since the U.S. patent specification contains citation information, many studies have favored using this citation information. Following results of this study are also obtained by analyzing citation information of the U.S. patent office between 1994 to 2014. Figure 4 shows the average CPP value by country during that period. Canada and Sweden have the highest CPP, followed by the U.S.. This implies that many outstanding patents that found implants technology are from the U.S. and Europe where the dental implants industry was born. The PII value which is the CPP value of a particular country divided by the average CPP of all countries is shown in Figure 5. Like CPP value, Canada, Sweden, and the U.S. have the top 3 places above average. Values of Switzerland, Germany and France are close to the average value 1.0, while Korea has the lowest value of 0.24 among 11 countries.

The TS indicator, the product of PII and the number of patents, supplements quantitative aspect to PII indicator which describes only the qualitative aspect. Figure 6 shows the

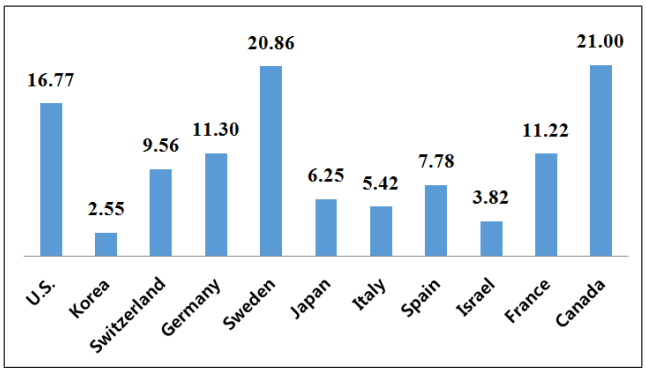

FIGURE 4. CPP value by country

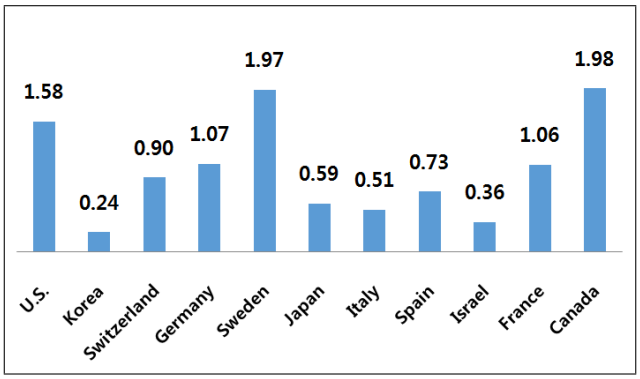

FIGURE 5. PII value by country

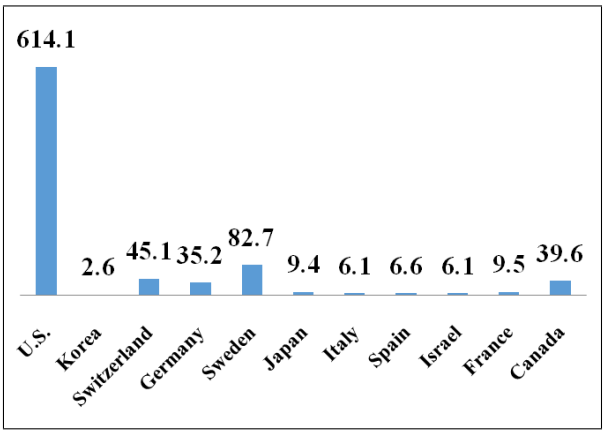

FIGURE 6. TS value by country

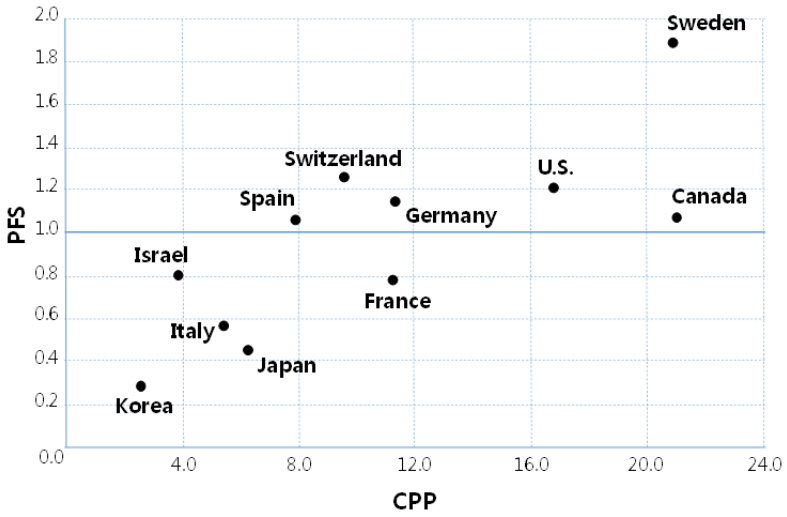

FIGURE 7. PFS vs. CPP

TS values of each country. Unlike PII value, the U.S. shows an overwhelming lead in TS value, while Korea still holds the lowest TS value. This result shows that Korean patents have minor impacts on global markets with relatively low importance. By placing PFS and CPP in 2-dimensional coordinates, as shown in Figure 7, each country's technological influence and its participation to global market can be compared. It looks Sweden, the U.S., and Canada in the upper right quadrant of Figure 7 are the technologically leading countries with strong influence and global market dominance. On the other hand, Korea, Israel, Italy, and Japan in the lower left corner of the Figure 7 show weaker technical influence and lower global market penetration than the other countries.

5. **Conclusions.** In this study, quantitative analysis was performed using patent data to assess the technological-level of top 11 countries in the dental implants industry. The U.S. has demonstrated a distinct dominance in all technology sectors of implants: fixture, abutment, and surface treatment. Korea and Japan have shown very focused and rapid growth in recent years at the surface treatment sector. Their focused R&D activities can also be confirmed by high RTA values of Korea and Japan that show specialization in surface treatment sector. Fixture and abutment are the basic sectors of dental implants that have been extensively studied since the beginning of the implants industry. Surface treatment is a recently emerging sector that needs many new technologies with huge market potentials. As a latecomer in the implants industry, focused R&D on surface treatment in Korea and Japan can be considered as a reasonable market entry strategy.

In the patent family analysis, Sweden and the U.S. showed strong presence at the global market, but Korea showed weakness with the lowest number of patent families and PFS value. Korea also has the lowest CPP, PII, and TS value among 11 countries, which testifies few impacts on dental implants technology. Although these results are based on the U.S. patent data, it still has much implication to understand technological-level of each country, given that the U.S. has the world's largest dental implants market. Further study that includes recent 5 years of patent data is needed to update latest technological trends in the dental implants industry.

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