Forecasting Dental Implant Technologies Using Patent Analysis

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***Abstract*--Technology development extends the frontier of knowledge and offers new economic opportunities. Global populations are experiencing increased longevity which in turn increases the need for new medicines, devices, and medical services. For example, the percentage of people with missing teeth is almost 10% with the largest number (over 5.5 billion) in Asia and Africa (Tsai et al., 2010). There is a significant market for newer, less expensive, and easier to place dental implants. This research studies dental implants to document the development and trends using time series and cluster analysis of patent data.**

The methodology uses a three step search strategy to define the target patent groups. The database is built using the United States Patent and Trademark Office (USPTO) online files and search engine. The first step defines the target patent groups using related dental implant key phrases. The second step analyzes the main assignees and builds a patent map of the patent metadata. The patent map analysis includes the trends of applications over time, the analysis of assignee activities, the countries of assignees, the forward citations, the analysis of inventors, and the analysis of techniques. The final step determines the quality of the target patent groups. In order to understand the content of the patents, this research ranks the quality levels within a matrix of technology functions. The proposed methodology analyzes the distribution of dental implants and the patent strategy of main assignees. Extracting high quality patents and building clusters of emerging technologies provides an opportunity for companies to explore opportunities for designing next generation dental implant technologies.

I. INTRODUCTION

Global populations are experiencing increased longevity as a result of technological innovations. These innovations extend the frontier of knowledge and provide new economic opportunities. According to a medical market survey, the value for medicine, devices and services is forecasted to increase from three trillion dollars in 2012 to four trillion dollars in 2017 (Global Information, 2012). The increasing longevity of populations is increasing the medical market demand. For example, over 10% of the global population has missing teeth with the largest number (over 5.5 billion) in Asia and Africa. Figure 1 shows the market value trends for dental implants. Even with the decreased growth rate for three years starting in year 2007 and ending in year 2009, the market value for dental implants has grown from millions of dollars to billions of dollars over the last ten years. For the same time period, the number of dental implant companies will triple to over 200 companies (Figure 2). The research selects dental implants as a research topic to provide an opportunity for medical device companies to explore next generation techniques and designs.

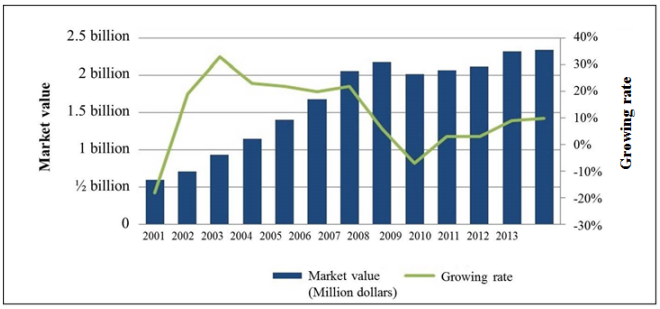

Figure 1 Market value for dental implants (Morgan Stanley, 2012)

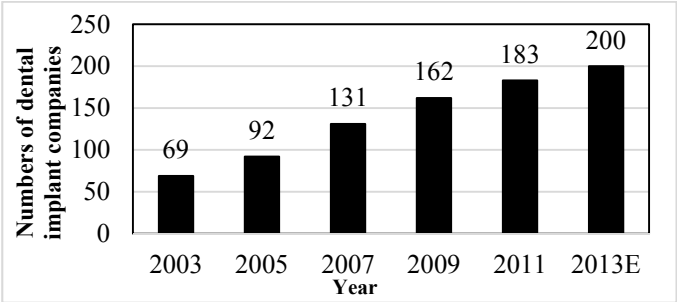

Figure 2 Growth of Dental Implant Companies (Morgan Stanley, 2012)

II. LITERATURE REVIEW

The academic literature introducing of dental implants and patent analysis are reviewed in this section. The literature review forms the research basis for the patent search strategy introduced in the methodology section.

A. Dental Implants

A dental implant is an artificial tooth root planted into the jaw to hold the prosthesis which replaces the missing tooth. The most common technologies for dental implants were developed by Per-Ingvar Brånemark and his team during the 1960s. The Swedish laboratory was the first to use titanium dental implants to replace human teeth. Most dental implant systems consist of the prosthetics, the abutment, and the implant body (Figure 3). The implant must be made from biocompatible materials to replace the natural root and decrease the rate of rejection.

The abutment is connected to the implant which sustains the load placed on the prosthetic. Dental implant procedures are divided into two stages. During first stage, the implant body (or fixture) with a healing abutment is implanted into the jaw. Once the implant is integrated inside the jaw after

bone growth and healing, the abutment is replaced with a permanent prosthetic crown that is attached during the second stage. The three categories of dental implant include endosseous implants, subperiosteal implants, and transosteal implants. Endosseous implants are made of metal or ceramic materials that are cylindrical shaped and are placed within the jawbone. Subperiosteal implants are metal frameworks that are attached on top of jawbone. Transosteal implants are either metal pins or U-shaped frames that pass through the jawbone and gum tissue. Endosseous implants are the most common and successful.

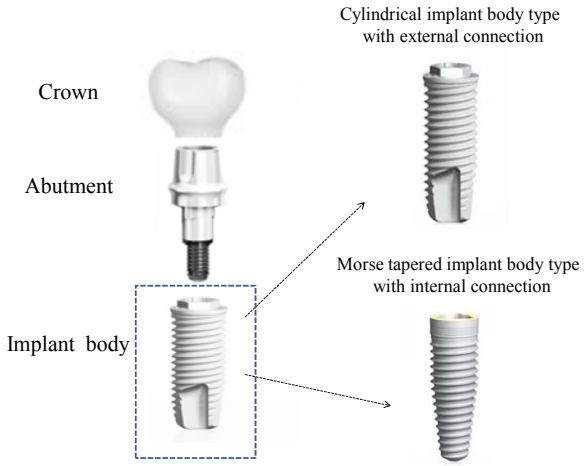

Figure 3 Key Structure of Dental Implant and Implant Body Types

B. Patent Analysis

Companies use patents to protect intellectual property rights and to build brand equity through research and development. The growth of the global medical market has directly increased the number of patents and trademarks. A report of World Intellectual Property Organization (WIPO) shows that the number of medical patents between 1995 and 2008 was competitive with the number patents for computer technology, and electric machinery and communication technology (Figure 4).

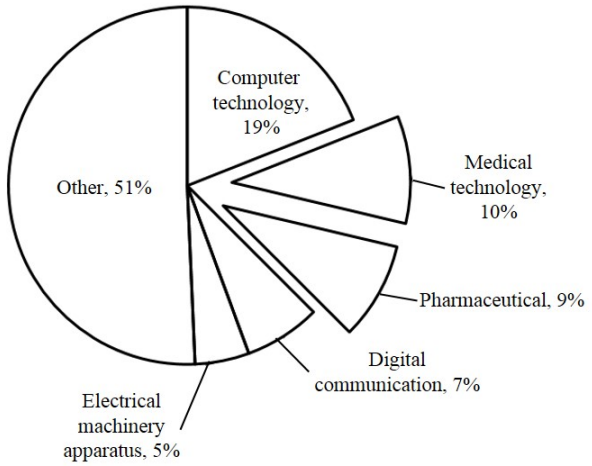

Figure 4 US Patent grow rate for years 1995 to 2008 (WIPO, 2011)

Patent documents use a structured format that facilitates systematic analysis. The patent format can be divided into two groups. The first group includes the structured metadata including the patent number, filing date, assignees, and the international patent classification code. The second group is less structured and use text and figures to describe the invention. The patent analysis process typically includes tasks such as searching, segmentation, abstracting, clustering, visualization, and interpretation (Tseng et al., 2007). Many patent analysis approaches have been developed. Yang et al. (2013) developed a patent analysis method to study the domestic performances and international competitiveness of China's electric vehicle technology. Park et al. (2013) proposed a function based patent analysis method to identify potential application areas of a technology under the open innovation paradigm. Trappey et al. (2012) use a patent quality methodology to automatically evaluate the quality of patents to reduce the resource requirements of domain experts to target high value patents for R&D commercialization and mass customization. Ko et al. (2014) developed a procedural method to analyze industry-wide technology diffusion of patent knowledge.

III. METHODOLOGY OF PATENT KNOWLEDGE EXTRACTION

The processes of extracting knowledge from patent documents to create an overview of technology used for dental implants are described in this section. The methodology of the research uses a three-step search process to define the target patent groups. The database is built using the United States Patent and Trademark Office (USPTO) online files and search engine. The first step is to find the target patent groups using related dental implant key phrases. The results were used in the second part of the process to analyze the main assignees and build a patent map of the metadata. The patent map analysis includes the trends of applications over the years, analysis of assignee activities, the countries of assignees, the forward citations, the inventor analysis, and an analysis of techniques. Finally, the quality of the target patent groups is measured to create a function-efficiency matrix.

Figure 5 depicts the three-step search strategy and its criteria and process. Note that the second step includes the related International Patent Classification Code (IPC) and repeats the patent search. The result of the combined search yields the main assignees for dental implants and the third and final search combines assignees and key phrases.

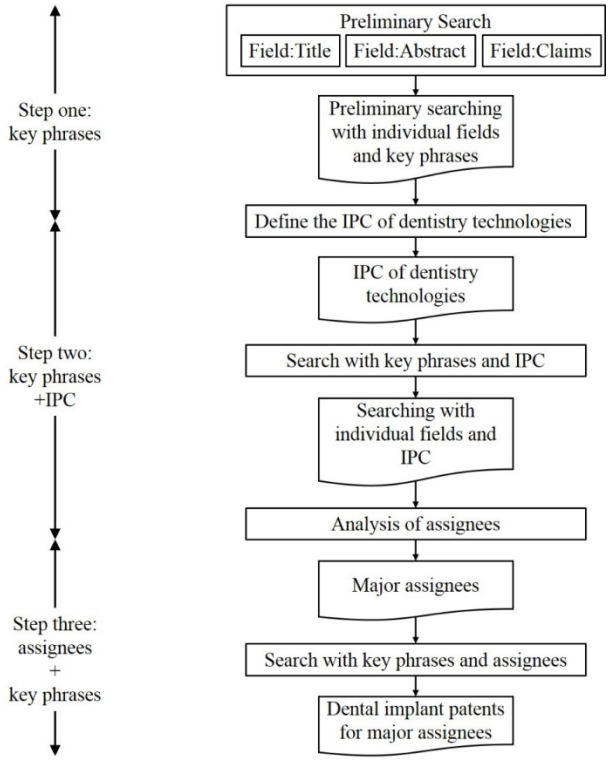

Figure 5 Patent search strategy and its criteria and process

IV. CASE STUDY OF DENTAL IMPLANT TECHNOLOGY DEVELOPMENT

This section presents a three part dental implant case study. First, the search uses the key phrases "dental implants," "oral implants," "implants," "teeth," and "tooth," from patent titles, abstracts, and claims. The queries of step one and the results are shown in Table 1. The query of titles is represented as "(TTL/implant and (TTL/dental or TTL/oral or TTL/tooth or TTL/teeth))", with a search yield of 876 patents. In order to reduce the search error, the maximum results from the patent claim field were used. The second step focuses on the classification of technology. The WIPO International Product Code (IPC) related to the classification of dentistry (A61C) and the code levels are shown in Figure 6.

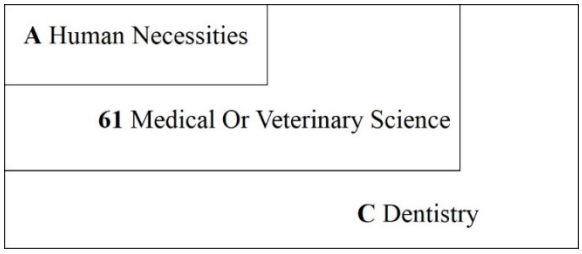

Figure 6 Definition of the WIPO IPC A61C

In order to include the related dentistry IPC from the patent claims, the next search uses the query "((ACLM/implant AND (((ACLM/dental OR ACLM/oral) OR ACLM/tooth) OR ACLM/teeth)) AND ICL/A61C$)" with the outcome of 1423 patents. Next, the assignees of patents are used to create a new target set of dental implant patents. The final results show five main assignees, including Biomet 3i (80 patents), Nobel Biocare (78 patents), Zimmer (73 patents), Astra Tech (40 patents) and Straumann (39 patents) forming a target patent group of 310 patents.

Figure 7 shows that the peak time of application is from years 1998 to 2002. However, the number of patent applications is currently decreasing. Straumann was the first of the top five assignees to apply for patents, while Nobel Biocare, Zimmer and Astra Tech began applications around the 1980s. Table 2 shows the analytical results for assignee activities. The average patent age is about 13 years for all assignees. Straumann holds the longest activity period but the shortest average age of patents.

TABLE 1 SEARCH RESULTS FOR STEP ONE

Query (TTL=title, ABST=abstract, ACLM=claims)	Results
(TTL/implant$ AND (((TTL/dental OR TTL/oral) OR TTL/tooth) OR TTL/teeth))	876 patents
(ABST/implant$ AND (((ABST/dental OR ABST/oral) OR ABST/tooth) OR ABST/teeth))	1571 patents
(ACLM/implant$ AND (((ACLM/dental OR ACLM/oral) OR ACLM/tooth) OR ACLM/teeth))	2824 patents

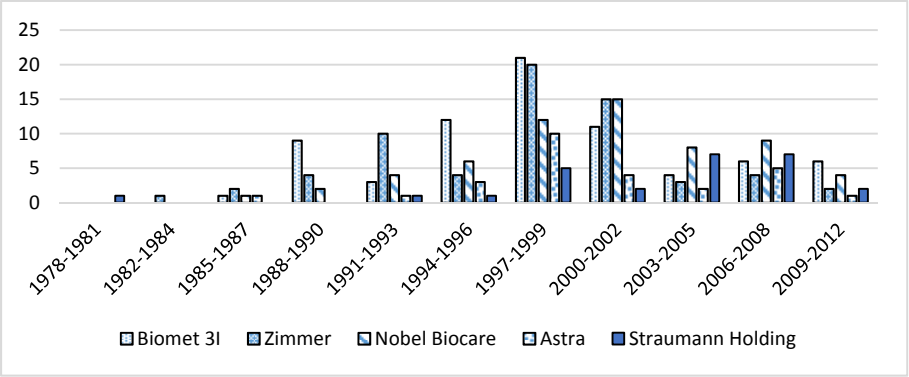

Figure 7 Trends of applications over the years for assignees

TABLE 2 ANALYSIS OF ASSIGNEE ACTIVITIES

Assignee	Number of Patents	Number of Countries	Number of Inventors	Average Patent Age
Astra Tech	30	2	59	13
Biomet 3i	77	1	196	14
Nobel Biocare	71	3	124	14
Straumann Holding	31	1	79	10
Zimmer	67	7	144	14

TABLE 3 THE COUNTRIES OF ASSIGNEES

Country	Number of Patents	Number of Assignees	Patents per Assignee
US (Florida)	77	1	77
Sweden	76	2	38
Canada	59	2	30
Switzerland	50	2	25
India	6	1	6
US (Nevada)	6	1	6

Table 3 represents the relationship between countries and assignees. The countries of assignees are US-Florida, Sweden, Canada, Switzerland, India and US-Nevada. Three countries had two assignees and the main assignees belong to international companies.

The inventor analysis shows that companies placed importance on protecting and retaining the inventors that filed patents under their corporate name (Table 4). Only the inventor Ajay Kumar changed companies and moved from Nobel Biocare to Zimmer.

The IPC of interest for dental implants is A61C8 (Human necessities; Medical or veterinary science; Dentistry). This classification includes implants fixed to the jaw bone for consolidating natural teeth or for fixing dental prostheses thereon) and includes 215 patents. The second classification is A61C13 (Human necessities; Medical or veterinary science; Dentistry; Dental prostheses) with 23 patents. The third is A61B17 (Human necessities; Medical or veterinary science; Diagnosis; Surgical instruments, devices or methods) with 9 patents.

The IPC is one of several classifications for patents. Other common classifications include the Unified Patent Court (UPC) and the Cooperative Patent Classification (CPC). CPC was developed under a joint partnership between the USPTO and the European Patent Office (EPO) to integrate the existing classification system. Table 5 lists the IPC, the UPC and the CPC of the target patents. The UPC set includes 433/172 (Dentistry; Prosthodontics; Holding or positioning denture in mouth) and 433/173 (Dentistry; Prosthodontics; Holding or positioning denture in mouth by fastening to jawbone). The CPC set includes A 61C 8/005 (Dental implant abutments connecting the upper structure with the implant).

TABLE 4 COMPANIES OF MAIN INVENTORS

Inventor \Companies	Biomet 3i	Nobel Biocare	Zimmer	Total
Beaty, K.D.	41	0	0	63
Lazzara, R. J.	35	0	0	53
Kumar, A.	0	11	6	51
Niznick, G. A.	0	0	15	43
Jorneus, L.	0	14	0	43
Porter, S. S.	12	0	0	37
Rogers, D. P.	11	0	0	37
Powell, T. M.	11	0	0	34
Day, T. H.	0	0	10	32
Wagner, W. R.	0	0	9	31
Total	110	25	40	175

TABLE 5 THE FOUR STAGE IPC PATENT SEARCH

IPC	Count	UPC	CPC
A61C8	215	433/173, 433/172, 433/213, 433/169, 433/214, 433/174, 433/165, 433/72	A 61C 8/005, A 61C 8/0048, A 61C 8/006, A 61C 8/0018, A 61C 8/0069, A 61C 9/002, A 61C 9/004, A 61C 13/0004
A61C13	23	700/163, 700/161, 433/173, 433/213, 433/173, 433/215, 433/223	A 61C 13/0004, G 05B 19/4207, A 61C 9/004, B 23Q 35/123, G 05B 19/4207, B 23Q 35/121 A 61C 8/005, A 61C 8/0018,
A61B17	9	606/86A, 606/304, 606/104, 606/300, 606/301, 606/316, 606/92	A 61B 2017/0256, A 61B 17/7032, A 61B 17/8875, A 61B 17/864, A 61F 2/0811, A 61B 17/863
A61F2	7	433/173, 433/174, 623/11.11, 606/60, 606/67, 606/70, 606/76, 623/1.1, 623/16.11, 623/2.1, 623/23.53, 623/23.57, 623/23.6	A 61C 8/005, A 61C 8/0018, A 61C 8/0069, A 61C 8/0022
A61C3	6	433/75, 433/166, 433/196, 433/215, 433/72, 433/142, 433/173	A 61C 1/084, A 61C 1/082, A 61C 8/0089, A 61C 3/06, A 61C 3/02, A 61C 17/005

Table 6 shows the average patent citations per year. Patent citations are an index of the frequency which related dental implant technologies are examined and referenced. Recent patents will not have sufficient lead time to gain large numbers of forward citations. The citations provide an indicator of the value of the disclosures based on earlier patents. The most frequently cited patent is US4758161 (cited 93 times) and is cited about 4 times per year. The second highest is US5622500 (49 times) and is cited about 3 times per year. These patents are quickly approaching expiration. The top three patents with the highest citations belong to Zimmer, which hold the critical technologies for dental implants. Further, the top ten most frequently cited patents belong to the classification A61C8/00 (fixed to the jaw bone for consolidating natural teeth or for fixing dental prostheses thereon).

Two companies hold the most important technologies in term of citations: Biomet 3i (13%) and Zimmer (12%). Although Zimmer hold 50 more patents than Biomet 3i, Biomet 3i holds the highest number of patents by assignees after they purchased many important patents from Implant Innovations. Table 7 shows the highest number of citations of patents by assignees. The average number of citations for the top five assignees is 4 times, Biomet 3i is 7 times, and Zimmer is 8 times which supports the high value of their patents.

Table 8 uses the patent citation information to build the backward and forward citation patent assignee matrix. The top forward citation company is Biomet 3i which was mostly cited by Nobel Biocare (46%) and their own patents (40%). The second and third largest forward citation companies are Nobel Biocare and Straumann Holding. The patents of Nobel Biocare and Straumann Holding are mostly cited by Biomet 3i and Nobel Biocare.

TABLE 6 RELATED DATA OF PATENTS' AVERAGE CITATION

Patent No.	Assignee	Countries	Inventor	IPC	Age	Citations	Average Citation per Year
US4758161	Zimmer	Canada	Niznick, G. A.	A61C8/00	26	93	4
US5622500	Zimmer	US (Nevada)	Niznick, G. A.	A61C8/00	19	49	3
US5433606	Zimmer	US (Nevada)	Niznick, G. A., Balfour, A. R.	A61C8/00	20	50	3
US5338196	Biomet 3i	US (Florida)	Beaty, K. D., Jansen, C. E.	A61C8/00	20	50	3
US5334024	Zimmer	US (Nevada)	Niznick, G. A.	A61C8/00	21	50	2
US5281140	Zimmer	US (Nevada)	Niznick, G. A.	A61C8/00	21	50	2

TABLE 7 HIGHEST CITATION NUMBER OF PATENTS BY ASSIGNEES

Assignees	Total Citation	Number of Patents	Citation Average	Highest Number of Patent Citations	Highest Citations per Total Patents (%)
Biomet 3i	499	77	6	10	13%
Zimmer	549	67	8	8	12%
Nobel Biocare	28	71	0. 4	0	0%
Straumann Holding AG	24	31	0.8	0	0%
Astra	24	30	0.8	0	0%
Total	1124	276	4	18	7%

TABLE 8 BACKWARD AND FORWARD CITATION ANALYSIS FOR PATENT ASSIGNEES

	A	B	C	D	Forward Total	Other Citations
A	4	5	0	0	9	5
B	24	71	83	1	179	108
C	3	33	37	0	73	36
D	5	14	7	5	31	26

A: Astra
B: Biomet 3i
C: Nobel Biocare
D: Straumann Holding

In this research, the 310 collected patents are analyzed using a text mining and clustering approach. The Naive Bayes classifier is used to assign document vectors and a vector space modeling is used to plot patent documents in n-dimensional space (where n is the number of key phrases). The application of different vectors, representing the appearances of key phrases in the documents, enables the relative positions of patent documents in n-dimensional space to be varied. Using a self-organizing mapping algorithm, the final n-dimensional model is converted into a two-dimensional map. The dental implant landscape map is generated using this method and is shown in Figure 8. The highest intensity peaks (nine clusters) in the landscape map represent the different sub-technologies of the dental patents and their related key phrases. These clusters include cluster 1 (for fixing to the jaw bone for consolidating natural teeth or for fixing dental prostheses thereon), cluster 2 (tools for fastening artificial teeth such as holders, clamps, or stands for artificial teeth), cluster 3 (apparatus for packaging, container, and sleeve), cluster 4 (apparatus or methods for oral or dental hygiene in dental prostheses), cluster 5 (apparatus including either dimensional or angular reference, or a surface adapted to be contacted by another device to govern the movement of the device), cluster 6 (subject matter wherein the denture is secured directly to the jawbone of the patient), cluster 7 (tooth drilling or cutting instruments and instruments acting like a sandblast machine), cluster 8 (prosthodontics for fixture, jawbone, and bone), and cluster 9 (dental tools or instruments).

In order to define the significant technologies of dental implants, the decision standard for patent quality include the type of patents (weight 0.2), the patent age (weight 0.5), number of claims (weight 0.15), and patentability requirements (weight 0.15). The research classifies of the quality level of the target patent groups. The quality levels range from one to ten, with the high levels indicating the greater importance of the dental implant technology domain. Figure 9 shows the patent number at each quality level and Figure 10 shows the patent number of each assignee ranked in the excellent level (patents of level eight to level ten). The target patent groups focus on the patent belongs to five assignees for a total of 286 patents.

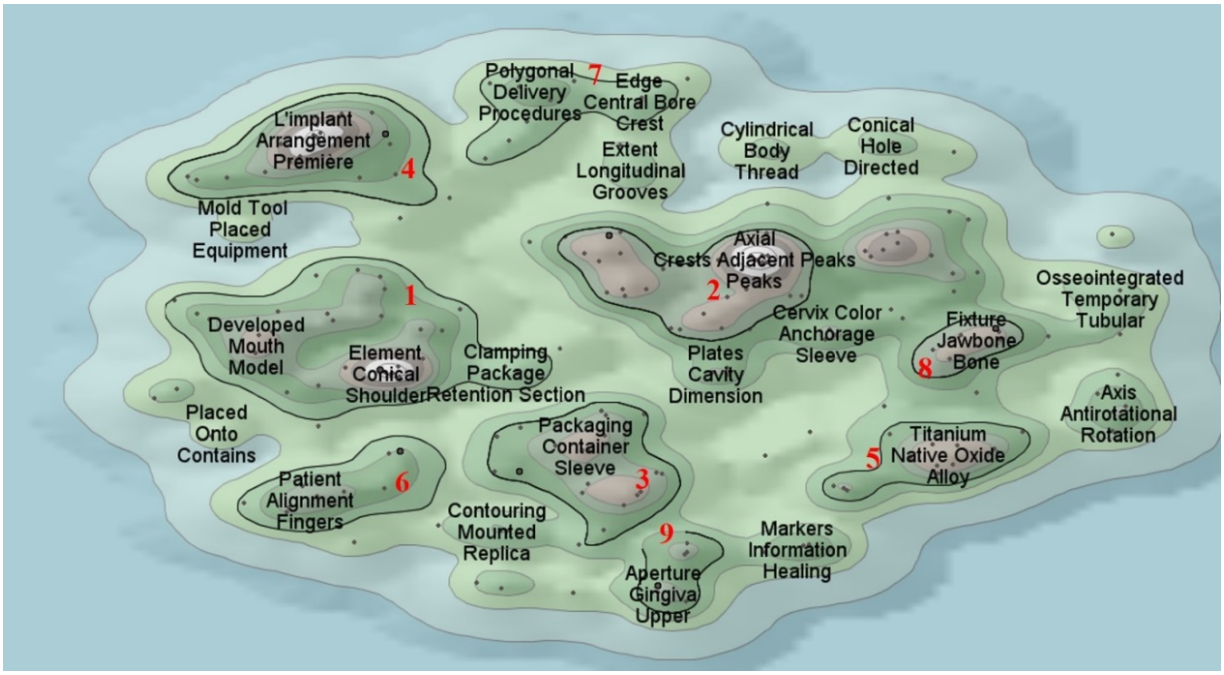

Figure 8 Dental implant landscape map

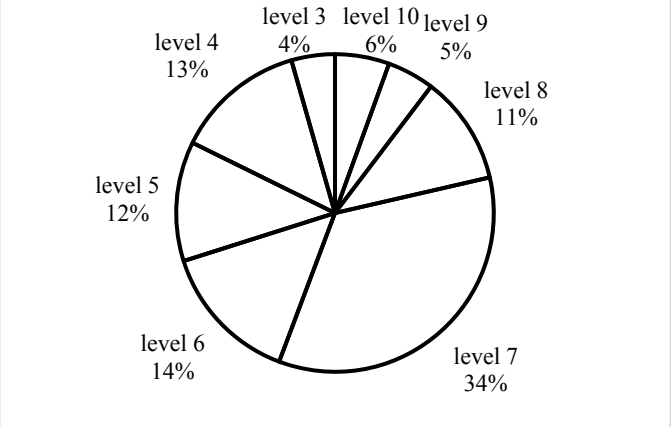

Figure 9 Number of patents within each quality level (excellent = 8, 9, 10)

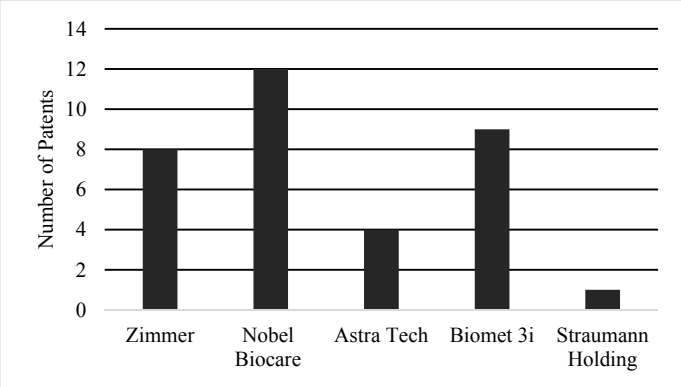

Figure 10 Number of patents by assignees in the excellent level

The research selects 34 patents rated as excellent, which includes the core technologies of dental implants, to build a function-efficiency matrix. The sub domains for dental implant technologies were categoried using the advice of dental experts and include the whole design (F1), dental implant and manufacture of its tools and equipment (F2), components (F3), tools for dental implants (F4) and the method of dental implant (F5) The whole design includes the design of dental implant systems and the implant designs. Dental implants and the manufacture of tools and equipment are either improvements or new inventions. The components contain abutments and implants. The tools include drilling and surgical devices and advanced methods for dental implants.

The efficiency measure includes biocompatibility (M1), stability (M2), reliability (M3), decreased side effects (M4), accuracy of manufacturing (M5), convenience of usage (M6), artistic design (M7), and accuracy (M8). The difference between stability and reliability are shown in Figure 11. Stability is the result of compressed bone holding the implant tightly in place or new bone cells forming at the site of the implant and osseointegration (ISQ, Scientific and Clinical Forum, 2014). Reliability indicates that the implant components of the dental system are tightly fastened together and are not easily loosened when chewing (TW M468294 U).

The research lists the sub technology classifications of 34 patents ranked in the excellent quality level (Table 9). Table 10 shows the relationship between different functions and the efficiency measure for the dental implant system. The efficiency of dental implant technologies determines whether there is an increase to stability and reliability. The main assignees for design are Zimmer and Nobel Biocare, for dental implant and manufacture of its tools and equipment is Nobel Biocare, for components are Nobel Biocare and Biomet 3i.

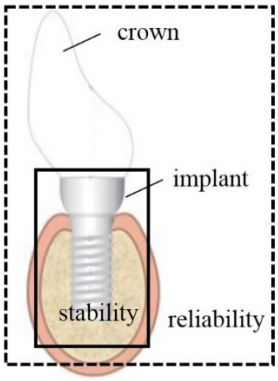

Figure 11 Stability and reliability of dental implant (ISQ, Scientific and Clinical Forum, 2014)

Table 11 shows the patent strategy of each assignee. The functions covered by Biomet 3i patents are ranked the highest followed by Zimmer, Nobel Biocare and Astra Tech. Moreover, 34 patents are ranked in the excellent quality level from 1992 to 2005. Twenty-four patents from 1992 to 1996 will expire (Astra has two patents, Zimmer has six, and Biomet and Nobel Biocare has eight patents), as shown in Table 12. These technologies will become open access for other enterprises and research organizations.

TABLE 9 TECHNOLOGIES CLASSIFICATION OF PATENTS IN EXCELLENT QUALITY LEVEL

Function	Patent
Whole design (F1)	5571016, 5433606, 7281925, 5989027, 7300284, 5571017, 5588838, 5695336
Dental implant and manufacture of its tools and equipment (F2)	5582299, 6821123, 7192445, 5440496, 5497336, 5286196, 5338196
Components (F3)	6824386, 5281140, 7175434, 5419702, 6790040, 5584694, 5702252, 5685714, 7066736, 7491058, 5622500, 5334024, 5674073, 5662474
Tool of dental implant (F4)	5575650, 5692904, 5685713
Method of dental implant (F5)	5364268, 5662476

TABLE 10 FUNCTION-EFFICIENCY MATRIX

	M1	M2	M3	M4	M5	M6	M7	M8
F1	2	5	0	1	0	0	0	0
F2	1	0	0	1	4	1	1	0
F3	3	7	6	1	0	0	0	2
F4	0	0	0	0	0	3	0	1
F5	0	0	0	1	0	1	0	0

TABLE 11 FUNCTION-ASSIGNEES MATRIX

	Zimmer	Nobel Biocare	Astra Tech	Biomet 3i	Straumann Holding AG
F1	2	2	1	1	1
F2	1	4	1	2	0
F3	4	5	1	4	0
F4	1	0	1	1	0
F5	0	1	0	1	0

TABLE 12 FUNCTION-YEAR MATRIX

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
F1	0	1	0	2	1	1	0	0	0	0	0	0	1	2
F2	2	1	2	1	0	0	0	0	0	2	0	0	0	0
F3	2	0	3	2	2	0	0	0	0	2	2	0	0	0
F4	0	0	0	3	0	0	0	0	0	0	0	0	0	0
F5	1	0	0	1	0	0	0	0	0	0	0	0	0	0

V. CONCLUSION

Dental implants is an important technology not only for older people but also for people in need of surgery due to trauma or birth defects. This research uses a three stage search strategy including key phrases, related IPC, and assignees to analyze the patent portfolio. The main assignees are Biomet 3i, Nobel Biocare, Zimmer, Straumann Holding and Astra Tech, the leading companies in dental implant market. The case study uses the patent search results to build a patent map to analyze the information about assignees, including the trends of applications over time, the analysis of assignee activities, the countries of the main assignees, the top five forward citation patents, the analysis of inventors, the IPC, the UPC and the CPC.

The countries of the primary assignees are US-Florida, Sweden, Canada, Switzerland, India, and US-Nevada. Dental implant innovation is growing in emerging countries such as India. The top five forward citation patents belong to Zimmer and Biomet 3i, which will soon expire and become open acccess. Given open access to expired patents, there should be new patent growth as innovators experiment and improve upon older designs in new markets. The largest number of patent citations belong to Zimmer and the high citation numbers for Zimmer and Biomet increase their patent value.

This research uses four decision policies to anaylsis the patent quality, including the type of patents, the patent age, the number of claims, and patentability requirements. A review of the landscape map for this technology reveals the key areas of interest include manufacturing of implants, components, and design. The high quality patents are categoried into five technology sub domains based on the advice of dental experts. Finally, understanding which patents will expire and become public indicates which technologies will form the basis for future innovation in new and emerging markets. Patent analysis helps researchers verify the technologies underlying dental implants and provide an opportunity for companies to explore the next generation techniques for dental implants. This paper used the five main assignees' patents as the target patent group. Future work will redefine the search strategy to focus on the new patents and product life cycles of dental implant companies using expired and open access technologies. The emerging innovation technologies will be used to study the development and changes to current business models and medical practices of developing economies.

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