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A knowledge centric methodology for dental implant technology assessment using ontology based patent analysis and clinical meta-analysis

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ABSTRACT

The medical equipment industry has been one of the fastest growing sectors of the decade with predicted global sales reaching US$ 430 billion in 2017 [22]. During the period from 1995 to 2008, the patent applications in medical technology increased rapidly worldwide (World Intellectual Property Organization, 2012). Patent analysis, although useful in forecasting technology development trends, has posed a challenging analysis task since the volume and diversity of new patent applications has surpassed the ability of regular firms and research teams to process and identify relevant information. Further, medical related technologies rely on clinical trials to validate and gain regulatory approval for patient treatment even though patents, protecting the intellectual property rights of inventors, have been granted. This research focuses on developing a knowledge centric methodology and system to analyze and assess viable medical technology innovations and trends considering both patents and clinical reports. Specifically, the design innovations of dental implant connections are used as a case study. A novel and generic methodology combining ontology based patent analysis and clinical meta-analysis is developed to analyze and identify the most effective patented techniques in the dental implant field. The research establishes and verifies a computer supported analytical approach and system for the strategic prediction of medical technology development trends.

1. Introduction

The World Health Organization [59] reported that about 30% of the population whose age is between 65 and 74 are likely to lose some of their natural teeth. Dental implants are a medical treatment with a range of products used to restore oral functions when losing teeth to caries, periodontitis, or accident. The global dental implant and prosthetics market was valued at US $ 6.8 billion dollars in 2011 and is expected to reach US $10.5 billion dollars in 2016 [5]. The surgical success and consumer acceptance have increased the global demand for implants and the prosthesis market. The demand for dental implants continues to attract companies and researchers to improve the design and development of dental implant components, devices, and techniques.

Modern dental implants have been used since the 1960s [1]. Since then, many improvements in dental implants have been introduced resulting in a variety of patents filed and granted. Fig. 1 depicts the number of patents related to dental implants in the United States Patent and Trademark Office (USPTO) from 1990 to 2012. Most dental implants consist of implant bodies (screws embedded in the jawbone), abutments (the platform for connection between the implant and crown), and crowns (the aesthetic and functional artificial replacement to the tooth). Many forms of dental implant connections have been developed as a critical part of dental implant R&D to improve torque transfer, gain stability between the implant body and the abutment, and subsequently minimize implant connection failure. Thus, this research focuses on the case study of dental implant connections to demonstrate the knowledge centric methodology of DS technology assessment and trend prediction.

The FDA [17] establishes regulations for dental implants abutments and enforces rigorous procedures of mechanical tests and clinical studies. However, there are still some implant designs in

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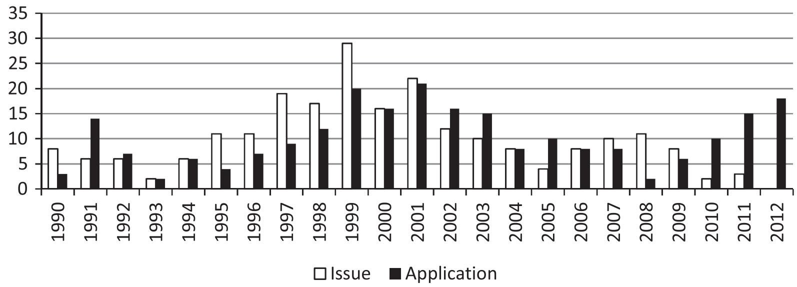

Fig. 1. US patents (1990 through 2012) filed and issued that are related to dental implants.

use with relatively high failure rates that pass the FDA regulations [46,2]. This research focuses on efficiently and accurately predicting medical technology trends with computer supported analyses of published patents and collective clinical trial literatures. Patent documents contain technical details of the innovations and inventions. In order to better understand the performance of new medical technologies and gain approval from regulatory agencies, reports of updated clinical trials on human subjects are also collectively analyzed. The objective of this research is to combine text mining, data mining, and meta-analysis within a specific domain, i.e., dental implant connections, including related patents and the corresponding clinical trials to better understand successful trends in medical technology innovation and adaptation.

2. Literature review

The literature related to dental implants, ontology, knowledge discovery, patent analysis and meta-analysis are discussed in this section. We first provide a brief background review of dental implants to provide a better understanding of the domain knowledge. The entire analytical procedure is based on domain specific (DS) ontology. The definition of ontology for knowledge representation and the ontology-based knowledge discovery applying text and data mining techniques are depicted in Sections 2.2 and 2.3. In Sections 2.4 and 2.5, macro- and micro-patent analyses and systematic meta-analysis of clinical literatures are described.

2.1. Dental implants

A dental implant is an artificial tooth root which is placed into a patient's jaw to hold a prosthesis replacing a missing tooth. Most dental implant systems consist of a crown, an abutment, and an implant body. Dental implant procedures are divided into two stages. First, the implant body is implanted into the jaw. Second, once the implant is stable inside the jaw bone, the abutment is connected to the implant body and the crown is attached to the abutment. The abutment is the component for connecting the implant body and the final outer crown or artificial tooth. The abutment usually connects to the implant body via a screw. One of the features which vary among dental implant systems is the type of connection that allows the abutments and prosthesis to be attached to the implant body. These connections include external connections, internal connections, or Morse taper connections [39] as shown in Fig. 2. Implant systems with external connections have a polygonal protrusion at the upper part of the implant body. For internal connections, the implant body has a notched polygonal cavity at the upper part which matches the polygonal protrusion at the abutment end. The internal hex connection combined with a Morse taper implant body is considered an alternative to the external hex implant [39]. Marginal bone loss (around the connection) is used as one of the most critical indicators of dental implant quality and long term stability (Papaspyridakos et al., 2012). New designs

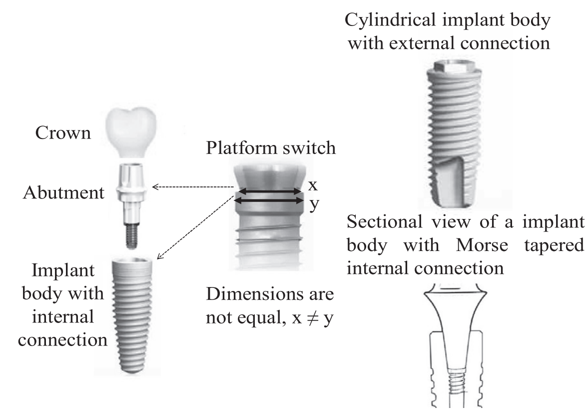

Fig. 2. Dental implant illustration and design variations.

of the implant-abutment interface, such as one-piece implants and platform switching (an implant body connected with a narrower abutment), have increased the success rate of implant technology [3]. However, the comparison of design effects has not been studied and there is no research demonstrating which design has a greater impact on implant quality and long term success.

2.2. Ontology

An ontology is an explicit specification of a knowledge domain and consists of a set of concepts, relations, objects and functions [24]. Another definition given by Grüninger and Fox [25] is the ontology is a formal description of a set of entities and their properties, behaviors and relations. Therefore, the ontology is considered to be a representational model of some portion of a real world knowledge domain [28] and is a set of objects and the relationships among these objects, which may be represented in the form of graphs and figures. The ontology types include terminology based ontologies, information ontologies, and knowledge modeling ontologies [26]. Domain ontologies focus on a specific field and describe the concepts of the domain entities as well as the attribute values and characteristics of the domain. Researchers focus on a specific domain through the visualization of knowledge, but there are no standard procedures to build specific ontology. Ding and Foo [15] define the methods used to construct an ontology as bottom-up, top-down and middle-off depending on how the ontology schema is initiated (e.g., bottom-up patching and synthesizing, top-down detailing and propagating, or working from both ends). The ontology reasoning technique is widely applied in the application of expert systems, artificial intelligence, and knowledge management in industry. Liou et al. [34] proposed a development procedure that includes planning, design, testing and modification, deployment, and integration to build an ontology based database. Trappey et al. [49] proposed a method for automatic patent document summarization which used ontology trees to automatically shorten patents into abstracts containing the key concepts of lengthy patent documents. Lin [32] used domain ontologies to classify and analyze the technology coverage of patents within companies. For specific dental implant domains, [53] define a domain ontology schema for patents search and analysis.

2.3. Knowledge discovery

Knowledge discovery is a process to extract implicit, previously unknown, and potentially useful knowledge from known data which are relevant and useful [18]. Depending on the data type, knowledge discovery is divided into two categories, i.e., discovering knowledge in a database (KDD or data mining) and in a textual document base (KDT or text mining). KDD is the process used to automatically discover previously unknown patterns, rules, and other types of content in large volumes of data [19,11]. The steps of KDD consists of identifying the analytical objectives, creating the target data set, cleaning and preprocessing data, data reduction or projection, using data mining techniques or algorithms to search the patterns of data, and interpreting the patterns [19].

Text mining is commonly known as knowledge discovery when analyzing documents or text [20]. The framework of text mining consists of text refinement and knowledge distillation [48]. Term frequency-inverse document frequency (TF-IDF) is a statistical method which uses the frequency of word occurrence in text to reflect the importance of a word in a given document set [45]. Salton and Buckley [44] reported that the length of a document can affect the term weight, therefore, TF-IDF was modified and called normalized term frequency-inverse document frequency (NTF-IDF). The number of words in a set of documents is used to normalize the value of term frequency. For patent analysis, text mining techniques, including text segmentation, summary extraction, feature selection, term association, cluster generation, topic identification and information mapping, are commonly applied [54]. Trappey et al. [49] combined the techniques of ontology based text mining and data mining to develop new methodologies for patent analysis and case study documentation.

2.4. Patent analysis

A patent is a form of intellectual property. Patent documents contain extensive information about the technology research and development results. Therefore, patents as knowledge documents are invaluable sources for investigating and analyzing new technologies and trends [31]. A typical patent analysis scenario includes tasks such as searching, segmenting, abstracting, clustering, visualizing, and interpreting technical texts [54]. The approaches used for patent analysis include patent maps, patent abstraction, patent clustering and classification, and rating patent quality. A patent map is a visual display of patent documents using graphic software [47]. The patent map helps companies differentiate designs and identify new design opportunities [6]. Since the number of patents continues to increase rapidly in world patent corpuses, automatic methods of extracting and synthesizing patent information and intelligence have become important strategic tools. The principle steps of document summarization are selecting key representative words via text mining and then generating sentences as the final document summary [4]. Document categorization (also called classification) is a method which assigns documents to pre-defined classes, whereas document clustering is a method of generating homogeneous sets according to a pre-specified properties or indices without pre-defined categories. Trappey et al. [52] applied ontology-based artificial neural networks to systematically and automatically categorize or classify patent documents. Further, Trappey et al. [50] proposed a non-exhaustive clustering methodology for automatically forecasting and analyzing technical trends to develop sustainable corporate R&D strategies. Patent quality represents the market value of patents. The quality of patents can be measured using combined indices, such as forward and backward citations, numbers of International Patent Classifications, numbers of US Patent Classifications, and numbers of claims [51,40] and [16].

2.5. Systematic meta-analysis of clinical reports

Meta-analysis is a research approach where previously published studies in a given domain are collected and analyzed to integrate findings using statistical analyses [10]. Meta-analysis provides summarized analytical results combining independently conducted studies. Meta analysis is commonly used to appraise, summarize, and communicate the statistical results of several similar studies [23]. Meta-analysis is useful and frequently applied to help researchers identify effective trends in a specific domain [30]. Meta-analysis is widely used in medical research because of the large volume of related clinical trials. If the data are related, a summary of effects can be quantitatively assessed using meta-analysis. But meta-analysis should only be conducted when the studies are similar between research questions, populations, and outcomes. The major challenge with meta-analysis is to summarize and synthesize the results across a diverse range of related studies that use different methodologies, samples, and experimental designs.

3. Methodology

The methodology for this research study includes a domain specific ontology based patent analysis of dental implant connections and a meta-analysis of the related clinical trials. An overview of the methodology flow is shown in Fig. 3. The individual steps are described briefly in the sub-sections and include the cited literature.

3.1. Domain specific patent analysis

The processes of extracting knowledge from domain specific patent documents are described in the following steps, i.e., collecting data, extracting key phrases, creating the domain ontology, and analyzing clusters of sub-technologies. This stream of analysis follows the detailed procedure and algorithms developed in one previous research [53]. Thus, the methodology will only be briefly described. First, the patent data collection procedure adopted in this study

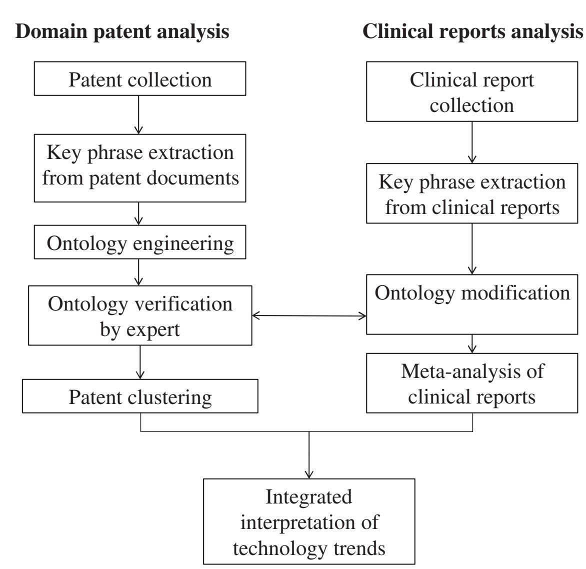

Fig. 3. The research framework and the methodology process diagram.

follows three steps. The first step is to search the patents from the USPTO database over a thirty-six year timeframe from 1976 to August 2012. The second step is to study the patent context and select the patents related to the domain of dental implant connections. Finally, a dental implant expert verifies the selected patents.

After collecting patents, the key phrases of the selected patents are extracted automatically using text mining techniques [56]. The key phrase extraction process produces a ranked list of the most frequently appearing phrases in the patents. Key phrases are ranked based on normalized term frequency (NTF) values in order to extract the common key phrases among the set of dental implant connection patents. NTF is the method used to calculate the frequency of a phrase among documents while the number of words in a document is used to normalize the term frequency. The NTF value of key phrases is computed using Eq. (1) where ntf_{jk} is the NTF value of term j in document k, tf_{jk} is the occurrence number of term j in document k, and dn_k is the total number of words in document k [44].

$$ntf_{jk} = tf_{jk} \times \frac{\sum_{s=1}^{N} dn_s}{N \times dn_k} \quad (1)$$

The formula used to calculate NTF-IDF value is shown in Eq. (2) where idf_j is the inverse document frequency of key phrase j. Given that df_j is the number of documents where the term j appears, the formula for inverse document frequency is computed using Eq. (3).

$$\text{NTF} - \text{IDF} = ntf_{jk} \times idf_j \quad (2)$$

$$idf_j = \log_2\left(\frac{N}{df_j}\right) \quad (3)$$

The domain-specific ontology, thereafter, can be built using the key phrases extracted automatically from the domain patents and verified by domain experts. The key phrases with strong associations are defined as concept relations which are automatically linked between key phrases. The concept relation links are also verified and modified by dental implant experts. Meantime, additional key phrases, found in the next stage clinical literature or identified by domain experts, can be added to enrich the ontology schema. Based on the built ontology, patents related to dental implant connections are collected and are further clustered using the K-means algorithm. The clusters are generated based on the patents' key phrase similarities. The key phrases representing each patent group are used to better describe the sub-technological attributes of the dental implant connections. The procedure for applying the K-means algorithm is summarized as follows:

1. Select K clusters as an initial partition;
2. Assign each patent to its closest cluster center to produce a new partition;
3. Compute new cluster centers of new partitions;
4. Repeat step 2 and step 3 until the cluster membership is stable.

3.2. Systematic clinical trial literature analysis

The second part of the research is to analyze the collection of clinical trial reports. The performance results of the patented technologies and the treatment effect sizes are compared across the clinical trial literature sample. The process consists of collecting as large and as comprehensive a sample of peer reviewed clinical trials as possible, extracting the key phrases of these reports, improving the domain-specific ontology by adding new key phrases derived from this literature, and performing the meta-analysis on the abstracted statistics.

The study first searches the literature of clinical trials for different technologies of dental implant connections archived in the PubMed database from January 1980 to November 2012. PubMed's primary data source is MEDLINE which covers the fields of dentistry, medicine, veterinary medicine, nursing, health care systems, and preclinical sciences. The key search phrases used are "implant connection" and "implant connection interface" and the type of publication is clinical trials. The papers related to dental implant connections are selected and further verified independently by the dental implant specialist who also reviewed the cited references within each paper for possible inclusion.

The list of the key phrases is generated using text mining techniques and the key phrases are ranked based on their normalized term frequencies (NTF) values [29]. After extracting the key phrases of the article, the common criteria for implant survival and the clinical trial evaluation parameters are incorporated into the dental implant connection ontology. The ontology is then corrected to include branches and nodes which represent the most effective clinical trials. The meta-analysis steps used in this study include defining the problem, collecting data, recording the characteristics of the clinical trials, and summarizing the results. The research questions are specified in a clear, unambiguous and structured form with a statement of the intervention, the patient demographics, and clinical outcomes.

The literature search strategy follows two steps which are the systematic electronic search and the independent manual search and verification. After the electronic database search of articles related to dental implants, an independent dental researcher eliminates articles which may be biased or poorly suited to the domain. A data extraction tablet is used to record information from the articles including authors, year of publication, follow-up period, implant system, site and number of implants, type of dental implant connection, and the survival rate of dental implants.

The findings from separate studies are aggregated using a three-stage quantitative assessment process. The first stage is to calculate the effect size and weight of each study. There are several types of effect size measures including risk difference and mean difference. Risk difference is a measure obtained by subtracting the risk of an event happening in one group from the risk in another group. The mean difference is obtained by subtracting the mean of an event happened in one group from the mean in another group. The formula used to calculate the risk difference and the standard error are shown in Eq. (4) and Eq. (5) where P_i^t is the proportion of events occurring in the treatment group, P_i^c is the proportion of events occurring in the control group, $SE_{RD,i}$ is the standard error of i-th study, N_i^t is the sample size of treatment group in the i-th study, and the N_i^c is the sample size of control group in the i-th study.

$$RD_i = P_i^t - P_i^c \quad (4)$$

$$SE_{RD,i} = \sqrt{\frac{P_i^t(1-P_i^t)}{N_i^t} + \frac{P_i^c(1-P_i^c)}{N_i^c}} \quad (5)$$

When the outcomes of the studies are continuous, the effect size is calculated as the mean difference. The formula is shown in Eq. (6) where M_i^t represents the treatment group and M_i^c represents the i-th study control group. SD_i is the standard deviation of either groups and $SE_{MD,i}$ is the standard error of i-th study. The values are computed using the formula shown in Eq. (7) and Eq. (8).

$$MD_i = M_i^t - M_i^c \quad (6)$$

$$SD_i = \sqrt{\frac{(N_i^t - 1) \times SD_i^{t^2} + (N_i^c - 1) \times SD_i^{c^2}}{(N_i^t + N_i^c - 2)}} \quad (7)$$

$$SE_{MD,i} = \sqrt{\frac{SD_i^{t^2}}{N_i^t} + \frac{SD_i^{c^2}}{N_i^c}} \quad (8)$$

The pooled effect sizes are aggregated using either the fixed-effect model or the random-effect model [27]. If the effect sizes are fixed, the effect sizes are pooled using the fixed-effect model. If the effect sizes vary from study to study, the pooled effect size should be calculated using the random effect model. The weight of the study is given using the inverse variance method. Therefore, a smaller variance yields a larger weight. The optimal weights are calculated using Eq. (9). The pooled effect size is a linear combination of weights and effect sizes as shown in Eq. (10). The standard error $SE_{\overline{ES}}$ of $\overline{ES}$ is computed using Eq. (11).

$$Wi = (SE_i^2)^{-1} \tag{9}$$

$$\overline{ES} = \sum_{i=1}^{k} \frac{W_i}{\sum_{i=1}^{k} W_i} \times ES_i \tag{10}$$

$$SE_{\overline{ES}} = \sqrt{\left(\sum_{i=1}^{k} W_i\right)^{-1}} \tag{11}$$

The heterogeneity of the effect size is tested with the hypothesis H_0: $ES_1 = ES_2 = \ldots = ES_k$ versus the alternative hypothesis that one ES_i differs from the remainder. The test of H_0 is based on the statistic Q which is shown in Eq. (12). If all k studies have equivalent effect sizes, then the test statistic Q has a chi-square distribution with $k-1$ degrees of freedom. On the other hand, if Q exceeds the $100(1-\alpha)\%$ critical value of a chi-square distribution with $k-1$ degrees of freedom, then the hypothesis is rejected.

$$Q = \sum_{i}^{k} W_i \left(ES_i - \frac{\sum_{i=1}^{k} W_i ES_i}{\sum_{i=1}^{k} W_i} \right)^2 \tag{12}$$

If the hypothesis is rejected, then the random-effects model is used to pool the effect sizes of the studies. In both the fixed and random effect models, the pooled effect size is computed using the weighted mean. For the random-effects model, the ES_i are not fixed and are considered not to have a chi-square distribution. Therefore, the variance τ^2 between studies should be calculated and the total variance is

$$SE_i'^2 = SE_i^2 + \tau^2 \tag{13}$$

where τ^2 is given by

$$\tau^2 = \begin{cases} 0, Q-(k-1)x<0 \\ \frac{Q-(k-1)}{\sum_{i=1}^{k} W_i - \sum_{i=1}^{k} W_i^2 \left(\sum_{i=1}^{k} W_i\right)^{-1}}, Q-(k-1) \geq 0 \end{cases} \tag{14}$$

and W_i are given in Eq. (15). The weights of studies in random-effect model are given by

$$W_i' = (SE_i'^2)^{-1} \tag{15}$$

The pooled effect size is given by

$$\overline{ES}' = \sum_{i=1}^{k} \frac{W_i'}{\sum_{i=1}^{k} W_i'} \times ES_i. \tag{16}$$

Table 1
Patents related to dental implant connections.

No.	US Patent No.	Title
1	US5100323	Dental implant
2	US5106300	Dental implant attachment structure and method
3	US5415545	Dental implant system
4	US5433606	Interlocking, multi-part endosseous dental implant systems
5	US5449291	Dental implant assembly having tactile feedback
6	US5704788	Dental implant abutment screw lock
7	US5733122	Dental implant attachment assembly including device and method for resisting loosening of attachment
8	US5759034	Anatomical restoration dental implant system for posterior and anterior teeth
9	US5904483	Dental implant systems and methods
10	US6419492	Dental implant system incorporating an external hex and Morse tapered walls
11	US6431867	Dental implant system
12	US6464500	Dental implant and abutment system
13	US6857874	Dental implant structure
14	US7014464	Multi-part abutment and transfer cap for use with an endosseous dental implant with non-circular, beveled implant/abutment interface
15	US7090495	Dental implant screw and post system
16	US7300282	Bio-functional dental implant
17	US7338286	Dental implant system
18	US7682152	Force distributing dental implant assembly
19	US8142193	Compound angular joint for connecting an abutment to a dental implant in a predefined angle
20	US8162663	Dental implant

Table 2
The matrix of normalized key phrase frequencies derived from the patent collection.

Key phrases	Patents																				NTF Sum
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Implant	72	105	113	197	136	87	48	146	85	210	175	152	78	95	95	78	150	23	93	222	2360
Screw	67	27	0	17	25	105	151	20	37	30	43	7	109	11	142	69	20	48	8	34	971
Dental implant	38	3	22	24	19	39	3	53	4	55	18	67	74	13	34	37	19	22	55	25	623
Cavity	0	2	0	78	0	0	0	3	8	74	0	0	0	0	0	4	47	11	0	91	317
Bone	50	3	0	6	18	4	0	13	7	11	63	20	0	0	0	14	7	27	11	20	274
Hexagonal	107	2	0	2	4	12	2	9	4	20	0	0	5	0	22	0	12	6	0	6	213
Fixture	0	0	0	0	0	23	0	89	0	0	0	0	64	0	4	0	0	0	0	0	179
Prosthesis	0	0	16	0	10	14	4	0	3	28	8	13	0	0	22	0	0	0	31	3	151
Splines	0	0	0	0	91	0	0	0	0	0	0	0	0	0	0	45	0	0	0	0	136
Crown	0	0	0	0	0	6	0	0	0	0	23	0	9	0	0	81	0	0	0	0	120
Protrusion	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	91

The standard error $SE'_{\overline{ES}}$ of mean effect size estimate $\overline{ES}'$ is the square root of its variance and is given by

$$SE'_{\overline{ES}} = \sqrt{\left(\sum_{i=1}^{k} W'_i\right)^{-1}}. \tag{17}$$

Finally, the results are pooled to calculate the estimated mean effect size. A forest plot [35] is used to illustrate and compare the relative strength of the treatment effects between studies.

4. Case study

The proposed methodology is applied to predict the technical trend for dental implant connections. The case study includes an ontology-based patent analysis and a clinical trial meta-analysis for the specific dental device domain.

4.1. Patent analysis of implant connections

The patents related to dental implant connections were collected and the key phrase descriptions of these patents were automatically extracted using text mining techniques to create the ontology diagram.

4.1.1. Patent data collection and the key phrases extraction

First, the patent documents related to dental implants were collected from the USPTO using the keyword “dental implant” for the search. As a result, a total of 564 patents were collected. The patent documents not related to dental implant connections were excluded. Next, the dental implant specialist verified the patents which were suitable for building the ontology of dental implant connections. As a result, 20 patents were selected as dental implant connection related patents. Table 1 summarizes the sample patent data. Table 2 presents the list of key phrases extracted automatically from related patents using the IPDSS software [57] with text mining technique described in Section 3.1.

4.1.2. Domain-specific ontology creation

Fig. 4 depicts the ontology schema of the dental implant connection technologies, consisting of key phrases that describe the key concepts and critical linkages between the implant body and the abutment. The ontology defines the structure of the dental implant and the types of connections. The ontology tree is divided into several parts. The sub ontology schema describes implant body, abutment screws, and the level of connections in the ontological hierarchy. The ontology is also used to identify the design variations as shown in Fig. 2.

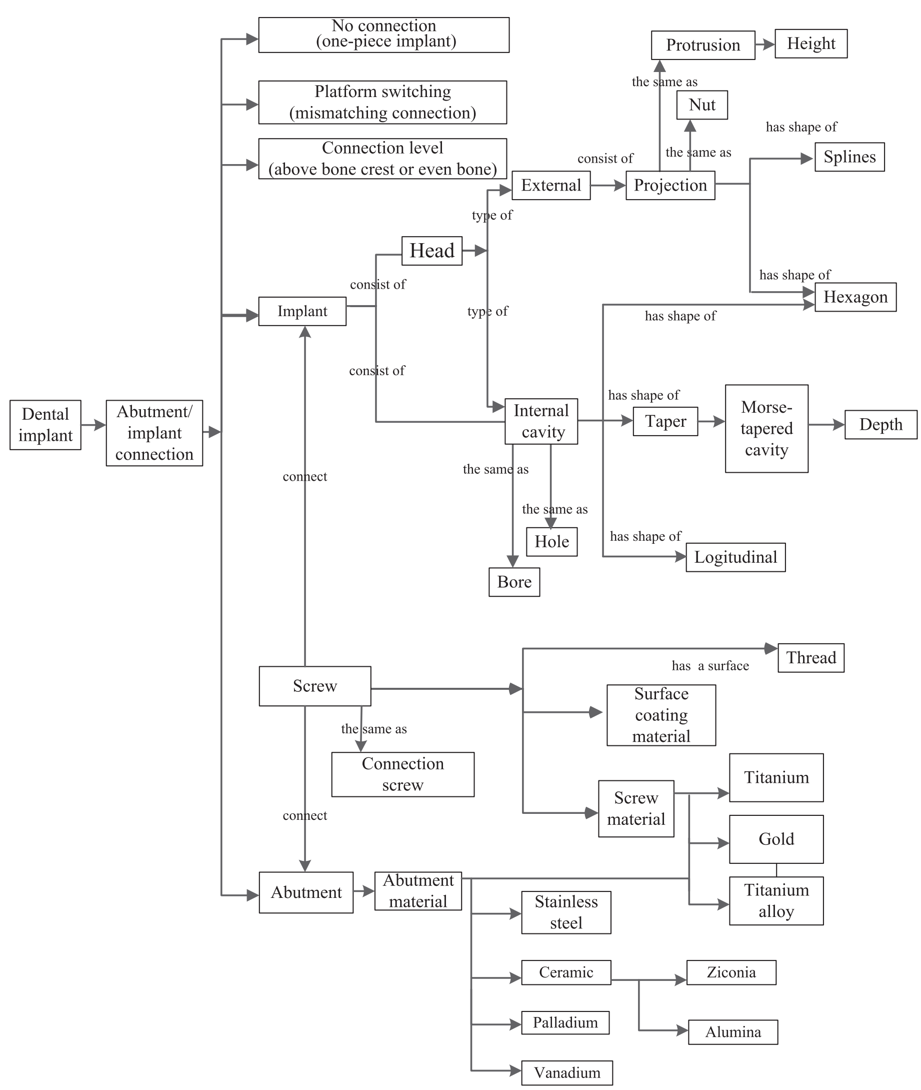

Fig. 4. Ontology schema for dental implant connections.

4.1.3. Sub-technology analysis

The training patents and the testing patents were collected and categorized into several groups. As a result, the patents were separated into 4 groups and the clusters are listed in Table 3.

The key phrases extracted from patents related to dental implants are shown in Table 4. There are several common key words in each cluster; e.g., dental implant, bone, and cavity, that are ineffective to identify the characteristics of a specific cluster. Therefore, key words appearing in two or more clusters are excluded. Cluster 1 is best described as containing patents related to one-piece abutments. The patents of Cluster 2 are related to the designs of internal implant connections. Cluster 3 contains patents related to connections, dental implant systems, and washers and therefore includes multi-feature implants. Cluster 4 is related to the characteristics of the connections between the abutments screw and implants. The results of the patent cluster analysis and the ontology schema reveal several key phrase groups including the characteristics of an implant head, connections, and one-piece abutments.

4.2. Analysis of clinical papers related to implant connections

The clinical trial papers are reviewed in order to compare the performance of designs related to the patent ontology. The meta-analysis results are used to summarize the effectiveness of the patented designs.

Table 3
Clustering results of implant connection patents.

Implant clusters	Training patents		Testing patents	
Cluster 1				
One piece abutments	US5040982	US6358050	US6857874	
	US5125839	US8057229		
Cluster 2				
Internal connections	US4758161	US7108510	US5759034	
	US5071350	US7665990	US6464500	
	US5399090	US7780447	US8142193	
	US6843653	US8123524		
	US7059855			
Cluster 3				
Multiple features	US4826434	US6168436	US5100323	US5904483
	US5071351	US7090493	US5106300	US7014464
	US5188800	US7104797	US5415545	US7090495
	US5435723	US7207800	US5704788	US7300282
	US5482463	US7708559	US5733122	US7682152
	US5636989	US8038442		
	US5810589	US8202088		
	US6068479			
Cluster 4				
Connections	US5195892	US7112063	US8162663	US6419492
	US5458488	US7484959	US5433606	US6431867
			US5449291	US7338286

4.2.1. Clinical paper collection

The electronic search for clinical trials used the PubMed database. The key phrases used for the search included "implant connection," "implant abutment interface," and the type of publications included were limited to human clinical trials. The articles retrieved were published between 1992 and 2012. After the initial electronic search, the abstracts and the content of the retrieved articles were independently analyzed by the dental implant specialist. The articles related to dental implant connections were archived and the key phrases were reviewed. The meta-analysis statistics were used to measure the effectiveness of the different patented designs. Finally, the clinical trials selected for the comparison of patented designs are shown in Table 5.

4.2.2. Key phrases extraction and ontology modification

The key phrases of the clinical trials related to dental implant connections were extracted. The full text of selected papers was analyzed and the key phrases were ranked based on their NTF value shown in Table 6. The key phrases with the greatest frequency of occurrence describe the common criteria for implant survival and the clinical trial evaluation parameters. These newly extracted key phrases were incorporated into the dental implant connection ontology with additional branches and nodes added to the schema indicating common criteria for clinical trials (Fig. 5).

4.2.3. Results of the clinical trial meta-analysis

The purpose of meta-analysis is to examine whether there are differences in survival rates and marginal bone loss between different types of patented dental implant connections. The following inclusion criteria were applied to select the clinical reports for the comparative meta-analysis between the treatment and the control groups.

1. A human study population.
2. The clinical trial includes the key words from the dental implant connection techniques ontology.
3. The type of publication is a clinical trial.
4. The minimal follow-up period was 1 year.
5. Only studies that provide sufficient data for coding and analysis are included.

A preliminary search found 48 related articles, but only ten studies were electronically chosen as valid reports that satisfy the above four criteria. A manual search was further conducted and an additional 5 studies were included in the meta-analysis yielding a total of 15 studies published between 2001 and 2012. Among the 15 articles, one study applied external connections, one study focused on internal (non-Morse taper) connections, five studies used Morse taper connections, and eight studies specifically compared dental implant connections with platform switch or platform match connections. The average follow-up period of

Table 4
Key phrases of dental implant connection patents clusters.

Cluster 1: One-piece abutments	Cluster 2: Internal connections	Cluster 3: Muti-features	Cluster 4: Connections
Converter	Tiltable	Plasma	Feedback
Inserting	Thermoplastic	Implant-abutment	Anti-rotation cavity
Slit	Trunco-conical	Longitudinally	Integrating
Supragingival	Joint	Cones	Conduit
Coronally	Adjustable	Tab	Non-curved
Triangle	Unthreaded	Non-circular	Sidewall
Frusto-conical	Heat-removable	Pocket	Morse
Bone-embedded fixture	Stability	Geometry	Interproximal
Alveolus	Coaxial	Dental implant-abutment	Tactile
One-piece	Frustoconical	Prosthetic device	Bone integrating
Aluminum oxide	Hex-shaped cavity	Washers	Extent

Table 5
Clinical trials related to dental implant connections.

No.	Studies	Title
1	Cooper et al. [7]	Treatment of edentulism using Astra Tech implants and ball abutments to retain mandibular overdentures
2	Drago [14]	A clinical study of the efficacy of gold-tite square abutment screws in cement-retained implant restorations
3	Donati et al. [12]	Immediate functional loading of implants in single tooth replacement: A prospective clinical multicenter study
4	Mangano et al. [36]	Prospective clinical evaluation of 1920 Morse taper connection implants: Results after 4 years of functional loading
5	Crespi et al. [8]	Radiographic evaluation of marginal bone levels around platform-switched and non–platform-switched implants used in an immediate loading protocol
6	Degidi et al. [9]	Prospective study with a 2-year follow up on immediate implant loading in the edentulous mandible with a definitive restoration using intra-oral welding
7	Mangano et al. [37]	Prospective clinical evaluation of 307 single-tooth Morse taper-connection implants: A multicenter study
8	Pieri et al. [43]	Influence of implant-abutment interface design on bone and soft tissue levels around immediately placed and restored single tooth implants: A randomized controlled clinical trial
9	Veis et al. [55]	Evaluation of peri-implant marginal bone loss using modified abutment connections at various crestal level placements
10	Linkevicius et al. [33]	Influence of thin mucosal tissues on crestal bone stability around implants with platform switching: A 1-year pilot study
11	Mangano et al. [38]	Morse taper connection implants supporting "planned" maxillary and mandibular bar-retained overdentures: A 5-year prospective multicenter study
12	Peñarrocha-Diago et al. [42]	Influence of implant neck design and implant–abutment connection type on peri-implant health. Radiological study

each study was between 1 and 5 years. Among the final fifteen clinical reports, there were seven observational studies conducted without control groups. Drago [14] used dental implants with external connections to study the effectiveness of Gold-Tite square abutment screws and reported that the survival rate reached 99% and the rate of abutment screw loosening was 0.96%. Norton [41] used dental implants with internal connections and the study revealed that the internal connections prevent mechanical complications such as abutment screw loosening or breakage. Döring et al. [13], Mangano et al. [36], Degidi et al. [9], Mangano et al. [37], and Mangano et al. [38] measured the performance of Morse taper connections for implants. Mangano et al. [37] reported that the rate of abutment screw loosening was 0.66%, which showed that Morse taper implants have higher mechanical stability and significantly reduced prosthetic complications [36]. Nonetheless, the clinical studies listed in Table 7 were not used to compare effect sizes since control groups were not used. Therefore, only studies with control groups and treatment groups were chosen for the meta-analysis. Table 8 lists the data extracted from the final sample of studies, which compared both implant failure rates and marginal bone loss as the performance indices. These studies applied platform switch connectors as the treatment groups and platform match connectors as the control group for the clinical trial.

For binary data, the risk difference was used to calculate the effect size and the event was defined as implant failure. There were 2 implant failures from platform switched implants and 3 implant failures from the platform match group. Table 9 shows the risk difference (RD) of individual studies. The analysis was based on the fixed-effect model. The pooled risk difference is 0.000 and the 95% confidence interval was between −0.012 and 0.012, and the *p*-value is 0.957 indicating that there was no significant difference between trials regarding implant failures. The relative strength of treatment effects in multiple quantitative studies and the pooled risk difference are shown in Fig. 6.

For marginal bone loss (MBL), the mean difference was used to compute the effect size. The mean difference was obtained by subtracting the mean MBL value from the platform switch group from the mean MBL value of the platform match group. Table 10 presents the mean differences from the individual studies. The random-effects model was used to aggregate the effect size. The variance τ^2 is 0.033. The meta-analysis results of the included studies are shown in Fig. 7 and the pooled mean difference is −0.33 mm and the 95% confidence interval was between −0.49 mm and −0.17 mm, and the *p*-value was less than 0.001. The result of the meta-analysis shows that the platform switch implant has significantly less marginal bone loss across the trials. This is a key finding since there are few studies reporting no significant differences in marginal bone losses between platform switch and platform match implant techniques.

The meta-analysis results revealed that the rates of implant failure were not significantly different between platform switch and platform match connections, while the platform switch connections consistently and significantly outperform platform match connections in preventing marginal bone loss.

Table 6
Key phrases derived from clinical papers of dental implant connections and their normalized term frequencies (NTF).

Key phrases	Clinical papers												NTF Sum
	1	2	3	4	5	6	7	8	9	10	11	12	
Marginal bone loss	0.0	0.0	22.4	0.0	0.0	0.0	0.0	22.0	10.1	5.1	0.0	0.0	59.5
Implant placement	5.7	0.0	4.7	0.0	6.6	5.7	0.0	8.7	0.0	0.0	4.1	19.3	54.7
Platform switching	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.0	0.0	0.0	32.1	40.8
Implant abutment connection	0.0	0.0	0.0	0.0	0.0	0.0	11.9	0.0	8.6	5.1	0.0	9.0	34.6
Abutment loosening	0.0	0.0	0.0	5.3	0.0	0.0	19.9	0.0	0.0	0.0	0.0	0.0	25.1
Marginal bone resorption	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.7	0.0	0.0	5.1	23.9
Morse taper connection	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	7.2	8.2	0.0	22.4
Abutment	0.0	0.0	14.0	0.0	0.0	19.5	0.0	0.0	0.0	0.0	0.0	0.0	33.5
Taper connection implants	0.0	0.0	0.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	15.2
Screw loosening	0.0	9.0	0.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.2
Edentulous mandible	3.4	0.0	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0	0.0	0.0	14.9
Microgap	0.0	0.0	0.0	7.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	14.0
Mandible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.1	0.0	13.1
Platform switched abutment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	13.0
Internal connection	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	5.8	0.0	0.0	12.1

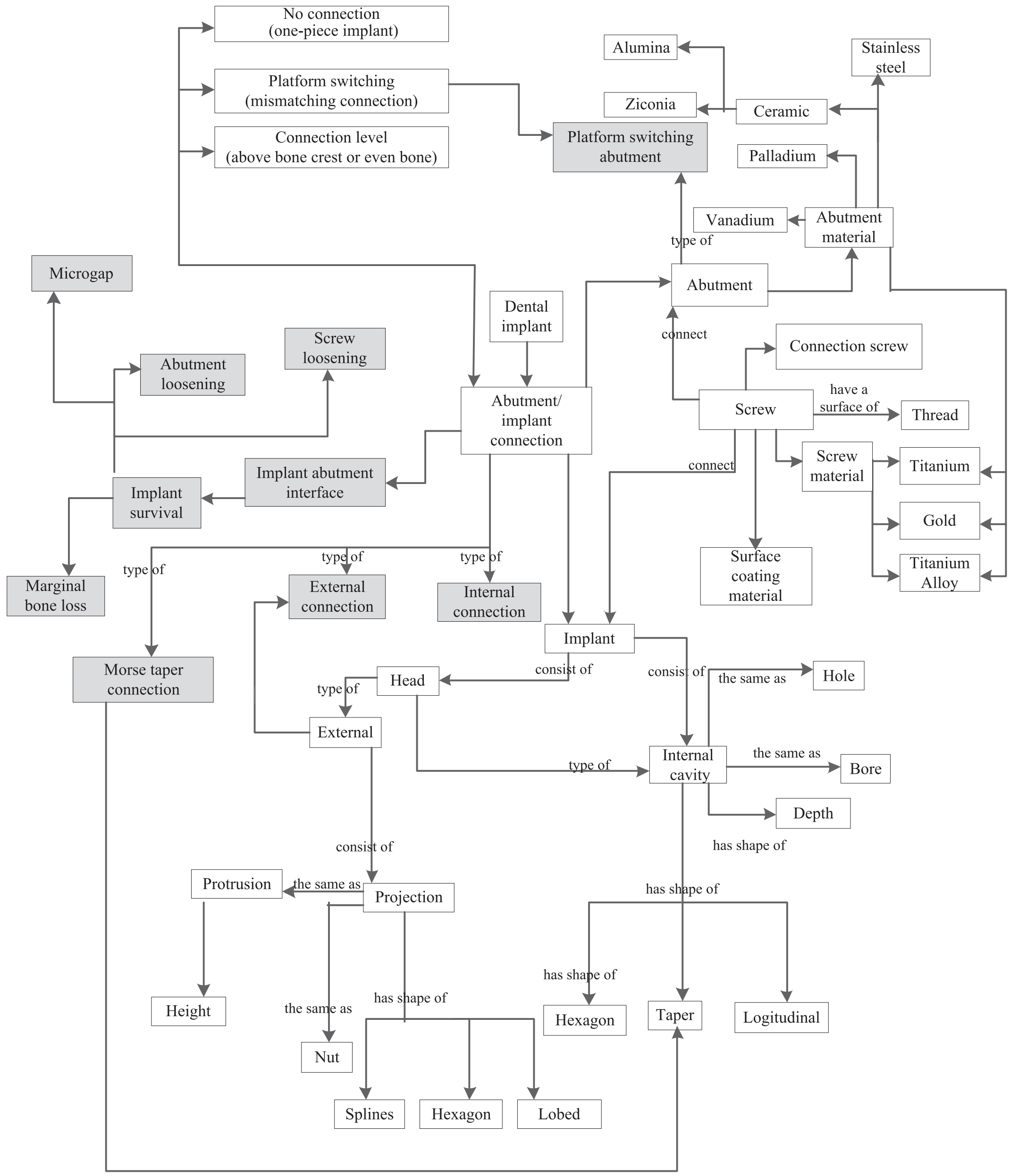

Fig. 5. Modified dental implant connection ontology.

Table 7
Prospective studies related to dental implant connections (without control groups).

Study	Follow-up period	Implant system	Position	No. of implants	No. of implants in the end	Survival rate
External connections						
Drago [14]	1 year	Implant innovations	Maxilla; Mandible	110	104	99%
Internal connections						
Norton [41]	5 years	Astra Tech	Maxilla	23	14 can be reviewed	n.r.[a]
Morse Taper connections						
Döring et al. [13]	38 months	Ankylos	Anterior and posterior jaw regions	275	270	98.2%
Mangano et al. [36]	4 years	Leone	Maxilla; Mandible	1920	1884	97.6%
Degidi et al. [9]	2 years	Ankylos	Mandible	80	80	100%
Mangano et al. [37]	4 years	Leone	Maxilla; Mandible	307	302	98.4%
Mangano et al. [38]	5 years	Leone	Maxilla; Mandible	288	282	98%

[a] n.r.: Not reported.

Table 8
Data extraction from the six clinical trials included in the meta-analysis.

Author(s)	Follow-up period	Implant system	Position	No. of patients	Connection type (No. of Implants)	No. of implants in the end	Marginal bone loss (Mean ± SD)	Survival rate (%)
Peñarrocha-Diago et al. [42]	1 year	Osseous;	Maxilla Mandible	18	Ext conn[a] (69)	68;	0.38 ± 0.51	98.6
		Inhex			Int conn PS[b] (72)	71	0.12 ± 0.17	98.6
Pieri et al. [43]	1 year	Samo Smiler System, BioS Park	Maxilla	40	Int conn[c] (20)	19;	0.49 ± 0.25	100;
					Int conn PS (20)	18	0.19 ± 0.17	94.7
Fickl et al. [21]	1 year	Osseotite Certain Biomet 3i	Maxilla Mandible	36	Ext conn (14)	14;	1.00 ± 0.22	100;
					Ext conn PS (75)	75	0.39 ± 0.07	100
Veis et al. [55]	2 years	Osseotite, Biomet 3i	Maxilla Mandible	n.r.	Ext conn (193)	193;	0.88 ± 0.85	100;
					Ext conn PS (89)	89	0.75 ± 0.55	100
Vigolo and Givani [58]	5 years	3i/ Implant Innovations	Maxilla Mandible	144	Ext conn (85)	85;	1.1 ± 0.3	100;
					Ext conn PS (97)	97	0.6 ± 0.2	100
Crespi et al. [8]	2 years	Seven Sweden & Martina; Ankylos Plus	Maxilla Mandible	45	Ext conn (34)	34;	0.78 ± 0.45	100
					Int conn PS (30)	30	0.73 ± 0.52	100

[a] Ext conn: External connection.
[b] PS: Platform switch.
[c] Int conn: Internal connection.

Table 9
Risk difference data of implant failure.

Study	Treatment group		Control group		RD	SE	*p*-Value	Weight
	No. of failures	No. of implants	No. of failure	No. of implants				
Peñarrocha-Diago et al. [42]	1	72	1	69	−0.001	0.020	0.976	1093.8
Pieri et al. [43]	1	19	2	20	−0.050	0.083	0.546	8402.9
Fickl et al. [21]	0	75	0	14	0.000	0.047	1.000	150.3
Veis et al. [55]	0	89	0	193	0.000	0.009	1.000	52.8
Vigolo and Givani [58]	0	97	0	85	0.000	0.011	1.000	145.4
Crespi et al. [8]	0	30	0	34	0.000	0.030	1.000	2517.5
Total					0.000	0.006		12362.7
$Q = 0.362$, Pooled RD = 0.000 (−0.012, 0.012), p-value = 0.957								

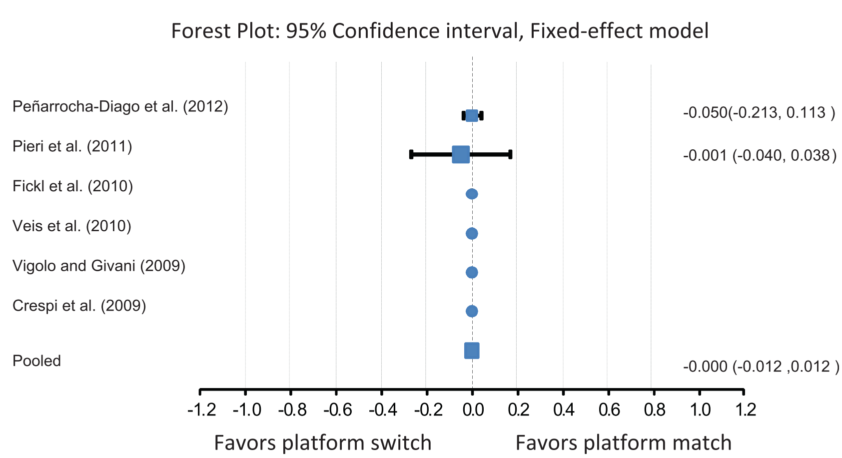

Fig. 6. Forest plot of implant failure risk differences.

4.3. R&D strategy and market opportunities

According to the results of the patent analysis, the types of dental implant connections were identified. Using the patent clustering results, the main sub-technologies of dental implant connections were identified. The patent groups included one-piece abutments, internal connections, multi-features and connection techniques. The results of the clinical literature text mining revealed that the dental implant evaluation parameters were based on implant failure rates and marginal bone loss. The marginal bone loss appears to be related to the implant-abutment interface. Few clinical studies reported significant advantages for platform switch implants in preventing marginal bone loss [8,55,33]. However, the results of the meta-analysis reveal that platform switch techniques do significantly reduce marginal bone loss levels when used for implant connections. Dental implants overall have a high survival

Table 10
Mean difference data for marginal bone loss.

Study	Treatment group			Control group			SD	MD[d]	SE	p-Value	W[e]	W'[f]
	N[a]	M[b]	SD[c]	N	M	SD						
Peñarrocha-Diago et al. [42]	71	0.12	0.17	68	0.38	0.51	0.37	−0.26	0.17	0.000	244.7	26.8
Pieri et al. [43]	19	0.2	0.17	18	0.51	0.24	0.20	−0.31	0.37	0.000	215.8	26.4
Fickl et al. [21]	75	0.39	0.07	14	1	0.22	0.11	−0.61	0.52	0.000	1034.9	29.3
Veis et al. [55]	89	0.75	0.55	193	0.88	0.85	0.77	−0.13	0.13	0.187	103.2	23.3
Vigolo and Givani [58]	97	0.6	0.2	85	1.1	0.3	0.25	−0.5	0.18	0.000	715.3	28.9
Crespi et al. [8]	30	0.73	0.52	34	0.78	0.49	0.50	−0.05	0.25	0.692	62.7	20.4
Total	381		412								2376.6	155.1
$Q = 60.07$, $\tau^2 = 0.033$, Pooled MD = −0.33 (−0.49, −0.17), p-value = 1×10^{-11}												

[a] N: number of implants.
[b] M: marginal bone loss value.
[c] SD: standard deviation.
[d] MD: mean difference.
[e] W: weight in fixed-effect model.
[f] W': weight in random-effect model.

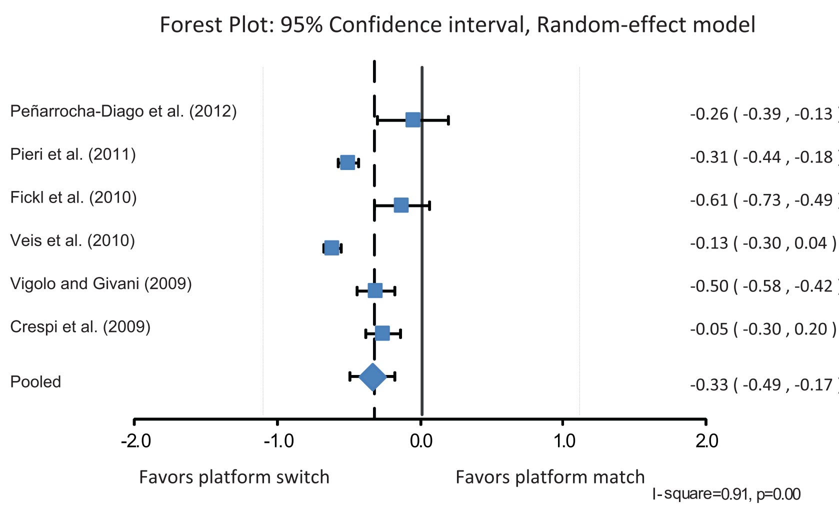

Fig. 7. Forest plot of mean differences in marginal bone loss.

rate regardless of design. However, preventing bone loss enhances the long term survival of the implant and improves the appearance of the replaced tooth. For dental implant professionals, the results demonstrate the significance of relating the performance of designs as an aid in the selection of improved dental implant products and techniques.

Given the newly discovered outcomes of clinical trial meta-analysis, the patent data set were further analyzed and separated into several groups depending on the types of implant connections. There were 14 external connection patents, 7 internal connection patents, and 3 platform switch patents included in the multi-features cluster. There were 3 external connection patents and 9 internal connections in the connections cluster. The average patent age of external connection patents is about 19 years, the average age of internal connection patents is about 13 years, and the average age of platform switch patents is the youngest (11 years). The number of external connection patent applications increased between 1989 and 1995 and decreased after 1995. The applications for internal connection patents have increased after the year 2000 with fewer platform switch patents being registered. The patent statistics indicate that the external and internal connection techniques are relatively mature technologies when compared to platform switch techniques.

By mapping the matrix of assignees and the numbers patent applications in sub-technologies (platform switch, internal connection platform match, and external connection platform match), the research identifies companies that dominate the market due to their patents and innovative dental implant connections. The dominant assignees are Nobel Biocare, Biomet 3i, Zimmer, Astra Tech, and Straumann. The patents of these five assignees cover the majority of internal connectors used for patient treatment. However, the internal connection patents of Zimmer have expired. The other four companies continue to file patents for internal connections. The external connection patents of Zimmer and Biomet 3i have expired indicating that there are few companies developing external connection implants. Nobel Biocare owns the patents for platform switch techniques. Companies interested in developing platform switch implant related products must fully understand the patents and products of Nobel Biocare to avoid patent infringement and intellectual property concerns.

5. Conclusions

This study proposes a methodology combining patent analysis and clinical meta-analysis. The critical text of patent documents is extracted using knowledge discovery to build the ontology. The ontology is validated by a dental expert and the construction of a visual map of key terms expresses and inter-relates the diverse terminologies from patent documents. The results help researchers utilize the knowledge of dental implant connections for further research and development. Meta-analysis provides a summary of the results from clinical trials which in turn is used to study the effectiveness of the related patents and implant designs. The research uses dental implants as a case study. The results help researchers and market analysts understand the implant connector market trends and determine the future design directions. In addition, the methodology developed in this research is broad enough to be applied to medical devices in general and can easily be extended to pharmaceutical products. The ability to link successful clinical trials and their effectiveness to patent designs and innovations provides a new means to access patent value.

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References

[1] R. Adell, U. Lekholm, B. Rockler, P.I. Brånemark, A 15-year study of osseointegrated implants in the treatment of the edentulous jaw, Int. J. Oral Surg. 10 (6) (1981) 387–416.
[2] T. Albrektsson, J. Gottlow, L. Meirelles, P.O. Ostman, A. Rocci, L. Sennerby, Survival of nobel direct implants: an analysis of 550 consecutively placed implants at 18 different clinical centers, Clin. Implant. Dent. Relat. Res. 9 (2) (2007) 65–70 (June).
[3] M. Bateli, W. Att, J.R. Strub, Implant neck configurations for preservation of marginal bone level: a systematic review, Int. J. Oral Max. Impl. 26 (2) (2011) 290–303.
[4] R. Brandow, K. Mitze, L.F. Rau, Automatic condensation of electronic publications by sentence selection, Inf. Process. Manage. 31 (5) (1995) 675–685.
[5] Ceramic Industry. (2012) "Dental Implants and Prosthetics Market Continues Growth." Available at: <http://www.ceramicindustry.com/articles/92515-dental-implants-and-prosthetics-market-continues-growth> (15.09.12).
[6] R. Chen, Design patent map visualization display, Expert Syst. Appl. 36 (10) (2009) 12362–12374.
[7] L.F. Cooper, M.S. Scurria, L.A. Lang, A.D. Guckes, J.D. Moriarty, D.A. Felton, Treatment of edentulism using Astra Tech implants and ball abutments to retain mandibular overdentures, Int. J. Oral Max. Impl. 14 (5) (1999) 646–653.
[8] R. Crespi, P. Capparè, E. Gherlone, Radiographic evaluation of marginal bone levels around platform-switched and non-platform-switched implants used in an immediate loading protocol, Int. J. Oral Max. Impl. 24 (5) (2009) 920–926.
[9] M. Degidi, D. Nardi, A. Piattelli, Prospective study with a 2-year follow-up on immediate implant loading in the edentulous mandible with a definitive restoration using intra-oral welding, Clin. Oral Implant Res. 21 (4) (2010) 379–385.
[10] R. DerSimonian, N. Laird, Meta-analysis in clinical trials, Control. Clin. Trials 7 (3) (1986) 177–188.
[11] V. Devedzic, Knowledge discovery and data mining in databases, Handbook Softw. Eng. Knowl. Eng. 1 (2001) 615–637.
[12] M. Donati, V. La Scala, M. Billi, B. Di Dino, P. Torrisi, T. Berglundh, Immediate functional loading of implants in single tooth replacement: a prospective clinical multicenter study, Clin. Oral Implant Res. 19 (8) (2008) 740–748.
[13] K. Döring, E. Eisenmann, M. Stiller, Functional and esthetic considerations for single-tooth Ankylos implant-crowns: 8 years of clinical performance, J. Oral Implantol. 30 (3) (2004) 198–209.
[14] C.J. Drago, A clinical study of the efficacy of gold-tite square abutment screws in cement-retained implant restorations, Int. J. Oral Max. Impl. 18 (2) (2003) 273–278.
[15] Y. Ding, S. Foo, Ontology research and development. Part 1 – a review of ontology generation, J. Inform. Sci. 28 (2) (2002) 123–136.
[16] H. Ernst, N. Omland, The Patent Asset Index – A new approach to benchmark patent portfolios, World Patent Inf. 33 (1) (2011) 34–41.
[17] FDA (2013). Guidance for Industry and FDA Staff – Class II Special Controls Guidance Document: Root-form Endosseous Dental Implants and Endosseous Dental Abutments – issued on May 12, 2004. Available at: <http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/ucm072424.htm> (10.12.13).
[18] W.J. Frawley, G. Piatetsky-Shapiro, C.J. Matheus, Knowledge discovery in databases: an overview, AI Magazine 13 (3) (1992) 57–70.
[19] U. Fayyad, G. Piatetsky-Shapiro, P. Smyth, From data mining to knowledge discovery in databases, AI Magazine 17 (3) (1996) 37–54.
[20] R. Feldman, I. Dagan, Knowledge discovery in textual databases (KDT), in: Proceedings of the First International Conference on Knowledge Discovery and Data Mining (KDD-95), Montreal, Canada, August 20–21, AAAI Press, 1995, pp. 112–117.
[21] S. Fickl, O. Zuhr, J.M. Stein, M.B. Hürzeler, Peri-implant bone level around implants with platform-switched abutments, Int. J. Oral Max. Impl. 25 (3) (2010) 577–581.
[22] Global Information, Inc., (2013) Medical Equipment Annual Deals Analysis: M&A and Investments Trends – 2012. Available at: <http://www.giiresearch.com/report/gd233652-medical-equipment-annual-deals-analysis-2012.html> (16.06.13).
[23] S. Green, Systematic reviews and meta-analysis, Singapore Med. J. 46 (6) (2005) 270–273.
[24] T. Gruber, Toward principles for the design of ontologies used for knowledge sharing, Int. J. Hum. Comput. Stud. 43 (5–6) (1993) 907–928.
[25] M. Grüninger, M.S. Fox, Methodology for the Design and Evaluation of Ontologies, in: International Joint Conference on Artificial Intelligence (IJCAI95), Workshop on Basic Ontological Issues in Knowledge Sharing, 1995.
[26] N. Guarino, Understanding, building and using ontologies, Int. J. Hum. Comput. Stud. Arch. 46 (2–3) (1997) 293–310.
[27] L.V. Hedges, J.L. Vevea, Fixed- and random-effects models in meta-analysis, Psychol. Methods 3 (4) (1998) 486–504.
[28] M.N. Huhns, L.M. Stephens, Personal ontologies, IEEE Internet Comput. 3 (5) (1999) 85–87.
[29] F.-C. Hsu, A.J.C. Trappey, C.V. Trappey, J.-L. Hou, S.-J. Liu, Technology and knowledge document cluster analysis for enterprise R&D strategic planning, Int. J. Technol. Manage. 36 (4) (2006) 336–353.
[30] K.S. Khan, R. Kunz, J. Kleijnen, G. Antes, Five steps to conducting a systematic review, J. R. Soc. Med. 96 (3) (2003) 118–121.
[31] S. Lee, B. Yoon, Y. Park, An approach to discovering new technology opportunities: keyword-based patent map approach, Technovation 29 (6–7) (2009) 481–497.
[32] T.-H. Lin, Using Data Mining Technique to Analyze LED Patent Litigation and Licensing Strategies, M.S. thesis, Dept. Industrial Management, National Taipei University of Technology, Taiwan, 2012.
[33] T. Linkevicius, P. Apse, S. Grybauskas, A. Puisys, Influence of thin mucosal tissues on crestal bone stability around implants with platform switching: a 1-year pilot study, J. Oral Maxillofac. Surg. 68 (9) (2010) 2272–2277.
[34] A.-H.A. Liou, Y.-T. Wang, K.-T. Lu, Collaborated construction and sharing of domain knowledge using ontology, J. Inform. Manage. Concepts Syst. Appl. 9 (2) (2007) 109–126.
[35] A.G. Lalkhen, A. McCluskey, Statistics V: introduction to clinical trials and systematic reviews, Cont. Educ. Anesth. Crit. Care Pain 8 (4) (2008) 143–146.
[36] C. Mangano, F. Mangano, A. Piattelli, G. Iezzi, A. Mangano, L. La Colla, Prospective clinical evaluation of 1920 Morse taper connection implants: results after 4 years of functional loading, Clin. Oral Implant Res. 20 (3) (2009) 254–261.
[37] C. Mangano, F. Mangano, A. Piattelli, G. Iezzi, A. Mangano, L. La Colla, Prospective clinical evaluation of 307 single-tooth Morse taper-connection implants: a multicenter study, Int. J. Oral Max. Impl. 25 (2) (2010) 394–400.
[38] C. Mangano, F. Mangano, J.A. Shibli, M. Ricci, R.L. Sammons, M. Figliuzzi, Morse taper connection implants supporting "planned" maxillary and mandibular bar-retained overdentures: a 5-year prospective multicenter study, Clin. Oral Implant Res. 22 (10) (2011) 1117–1124.
[39] P. Narang, H. Gupta, A. Arora, A. Bhandari, Biomechanics of implant abutment connection: a review, Indian J. Stomatol. 2 (2) (2011) 113–116.
[40] F. Narin, Patent bibliometrics, Scientometrics 30 (1) (1994) 147–155.
[41] M.R. Norton, Biologic and mechanical stability of single-tooth implants: 4- to 7-year follow-up, Clin. Impl. Dent. Related Res. 3 (4) (2001) 214–220; P. Papaspyridakos, C.-J. Chen, M. Singh, H.-P. Weber, G.O. Gallucci, Success criteria in implant dentistry: a systematic review, J. Dent. Res. 91 (3) (2012) 242–248.
[42] M.A. Peñarrocha-Diago, A.J. Flichy-Fernández, R. Alonso-González, D. Peñarrocha-Oltra, J. Balaguer-Martínez, M. Peñarrocha-Diago, Influence of implant neck design and implant-abutment connection type on peri-implant health. Radiological study, Clin. Oral Implant Res. (2012), http://dx.doi.org/10.1111/j.1600-0501.2012.02562.x.
[43] F. Pieri, N.N. Aldini, C. Marchetti, G. Corinaldesi, Influence of implant-abutment interface design on bone and soft tissue levels around immediately placed and restored single-tooth implants: a randomized controlled clinical trial, Int. J. Oral Max. Impl. 26 (1) (2011) 169–178.
[44] G. Salton, C. Buckley, Term-weighting approaches in automatic text retrieval, Inf. Process. Manage. 24 (5) (1988) 513–523.
[45] G. Salton, C.S. Yang, On the specification of term values in automatic indexing, J. Doc. 29 (4) (1973) 351–372.
[46] M.S. Schwarz, Mechanical complications of dental implants, Clin. Oral Implant Res. 11 (Suppl 1) (2000) 156–158.
[47] B. Shneiderman, The next generation of graphical user interfaces: information visualization and better window management, Displays 17 (34) (1997) 125–129.
[48] A.H. Tan, Text mining: the state of the art and the challenges, Proc. PAKDD Workshop Knowl. Discov. Adv. Databases (1999) 71–76.
[49] A.J.C. Trappey, C.V. Trappey, C.Y. Wu, Automatic patent document summarization for collaborative knowledge systems and services, J. Syst. Sci. Syst. Eng. 18 (1) (2009) 71–94.
[50] C.V. Trappey, A.J.C. Trappey, C.-Y. Wu, Clustering patents using non-exhaustive overlaps, J. Syst. Sci. Syst. Eng. 19 (2) (2010) 162–181.
[51] A.J.C. Trappey, C.V. Trappey, C.-Y. Wu, C.-W. Lin, A patent quality analysis for innovative technology and product development, Adv. Eng. Inform. 26 (1) (2012) 26–34.
[52] A.J.C. Trappey, C.V. Trappey, T.-A. Chiang, Y.-H. Huang, Ontology-based neural network for patent knowledge management in design collaboration, Int. J. Prod. Res. 51 (7) (2013) 1992–2005.

[53] C.V. Trappey, J.-M. Wang, S. Hoang, A.J.C. Trappey, Constructing a dental implant ontology for domain specific clustering and life span analysis, Adv. Eng. Inform. 27 (2013) 346–387.

[54] Y. Tseng, Y. Wang, Y. Lin, C. Lin, D. Juang, Patent surrogate extraction and evaluation in the context of patent mapping, J. Inform. Sci. 33 (6) (2007) 718–736.

[55] A. Veis, N. Parissis, A. Tsirlis, C. Papadeli, G. Marinis, A. Zogakis, Evaluation of peri-implant marginal bone loss using modified abutment connections at various crestal level placements, Int. J. Periodont. Rest. Dent. 30 (6) (2010) 609–617.

[56] S. Weiss, N. Indurkhya, T. Zhang, F. Damerau, Text Mining Predictive Methods for Analyzing Unstructured Information, Springer, Berlin, 2005.

[57] Wheeljet.com, IPDSS – Intellectual Property Defense Support System, 2013. Available at: <http://www.wheeljet.com.tw/edu/> (6.12.13).

[58] P. Vigolo, A. Givani, Platform-switched restorations on wide-diameter implants: a 5-year clinical prospective study, Int. J. Oral Max. Impl. 24 (1) (2009) 103–109.

[59] World Health Organization (2012) "Oral health." Available at: <http://www.who.int/mediacentre/factsheets/fs318/en/> (1.12.12).