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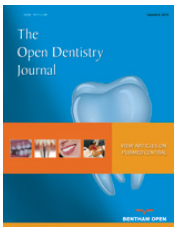

Finite Element Analysis Generates an Increasing Interest in Dental Research: A Bibliometric Study

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Abstract:

Purpose:

The purpose was to provide a longitudinal overview of published studies that use finite element analysis in dental research, by using the SCI-expanded database of Web of Science® (Thomson Reuters).

Material and Methods:

Eighty publications from 1999-2000 and 473 from 2009-2010 were retrieved. This literature grew faster than the overall dental literature. The number of publishing countries doubled. The main journals were American or English, and dealt with implantology. For the top 10 journals publishing dental finite element papers, the mean impact factor increased by 75% during the decade.

Results:

Finite elements generate an increasing interest from dental authors and publishers worldwide.

Keywords: Bibliometrics, dental research, dentistry, finite element analysis, journal impact factor, trends.

INTRODUCTION

Dental applications of finite element (FE) analysis have grown exponentially in the last decade as a way to assess the mechanical behavior of dental materials, teeth and implants. Finite element analysis is a computer-based method that calculates stresses and strains in computer-aided design models. It does so by splitting complex calculations into a large number of simple equations [1 - 3]. Software programs used to perform FE analysis are based on models of partial differential equations with boundary conditions. The simplification inherent in FE analysis has several limitations considering the linear simulation of material properties, interrelations and geometries. Nevertheless, these programs enable accurate comparison of models, which approach closer to reality as the calculation power of computers increases [4, 5]. Structural modeling is getting faster with graphical interfaces and tools for computer aided design. The evolution of dental materials, prosthodontics and orthodontics has created a stimulating environment in which to use FE analysis in dental biomechanics.

Dental literature involving FE analysis has also grown because of the increase of authors. All around the world, many dental researchers have learned how to use FE analysis software. Indeed the increasing accessibility of

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informatics has led more countries to compete in the computer-based research. In addition, many other dental researchers have preferred collaborating with FE-skilled people. As a matter of fact, mastering the software can be a long and demanding process. But at the end, all these researchers are authors trying to find out the most relevant journal, and to maximize the impact on their field. Papers involving FE analysis are now very common in dental research, and young researchers may wonder if specialised journals are not overwhelmed by FE studies. Unfortunately to our knowledge, a study providing a longitudinal overview of dental FE-related (DFE) literature does not exist.

The aforementioned question prompted us to investigate whether authors and publishers in dental research are still interested by FE papers. This bibliometric study sought to quantify the evolution of the DFE literature during the last decade (from 1999 to 2010) using the SCI-expanded database of Web of Science® (WoS, Thomson Reuters).

MATERIAL AND METHODS

The data for this study was obtained in November 2011 from the SCI-expanded database of Thomson Scientific Web of Science™ (WoS). To retrieve a comprehensive set of DFE literature, all primary articles or reviews published in journals with at least "finite element" and one of the following keywords in the titles/abstracts were included: endodont*, dentist*, dental, periodont*, temporomandibul*, gingiv*, molar, incisor, "alveolar bone", orthodont*, dentin*, enamel, maxillar*, mandibul*, oral, caries, lingual, jaw, "root canal", prosthodont*, denture, premolar, where the asterisk replaces any subsequent string of characters.

Data sets were selected, analyzed, and ranked in decreasing order of productivity by country and journal, using Microsoft Excel. Multi-authored publications were assigned equally to each country appearing in the author address field. Finally, publications from England, Wales, Scotland, and Northern Ireland were collectively assigned to the United Kingdom.

RESULTS

DFE Literature Grew Exponentially and Faster than the Overall Dental Literature (Fig. 1)

Dental-related FE literature increased 10-fold faster than the overall scientific literature between 1991 and 2010 (from 12 to 257 papers: 21 fold, and from 689,645 to 1,436,479 papers: 2 fold, respectively). Dental-related FE literature has grown exponentially since 1991, and even faster than the dental literature (which also increased exponentially) during the last decade. The overall scientific literature and FE literature since 1991 increased linearly in time. The first DFE papers appeared in 1973, eight years after the first FE papers.

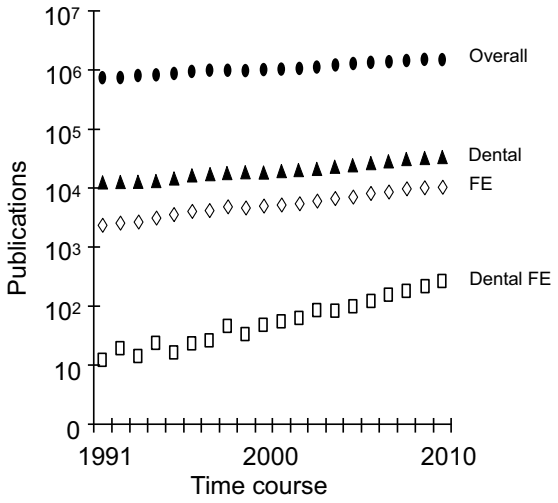

Fig. (1). Trends of publication productivity in the scientific literature involving finite element and the field of dentistry during the period 1991-2010. Dental: dental literature, FE: FE literature, DFE: dental literature involving finite elements analysis, Overall: scientific literature.

The DFE literature is not the only responsible of the global FE literature increase during the last decade, as DFE literature represents only 2.5% in 2010.

The Number of Publishing Countries Doubled in One Decade (Table 1)

The number of DFE publications retrieved and analyzed was 80 in 1999-2000 and 473 in 2009-2010. The percentage of DFE publications that was review articles remained stable between the two time periods (5% each). The percentage of DFE papers written in English grew from 97.5% to 99% in the WoS database over the decade (data not shown).

Table 1. Distribution of DFE papers among countries during the periods 1999-2000 and 2009-2010.

1999-2000				2009-2010				
Country/Territory	**# Papers**	**% of 80**	**Rank**	**Country/Territory**	**# Papers**	**% of 473**	**Rank**	**IF (average)**
World	80	100.0		World	473	100.0		1.868
European Union	31	38.7		European Union	142	30.0		2.048
USA	26	32.5	1	USA	104	22.0	1	2.252
United kingdom	10	12.5	2	China	89	18.8	2	1.729
Turkey	6	7.5	3	Brazil	58	12.3	3	1.764
Switzerland	6	7.5	3	Japan	50	10.6	4	1.504
Netherland	6	7.5	3	Germany	33	7.0	5	2.134
China (Taiwan)	5	6.3	6	Italy	25	5.3	6	2.005
Germany	5	6.3	6	Australia	21	4.4	7	2.434
Japan	5	6.3	6	Turkey	21	4.4	7	1.452
Canada	3	3.8	9	United Kingdom	20	4.2	9	2.385
Belgium	3	3.8	9	South Korea	16	3.4	10	1.826
France	2	2.5	11	Spain	13	2.7	11	2.051
Italy	2	2.5	11	Switzerland	13	2.7	11	2.847
Iran	1	1.3	13	Belgium	12	2.5	13	2.736
Poland	1	1.3	13	France	12	2.5	13	1.689
Thailand	1	1.3	13	Canada	10	2.1	15	1.339
Denmark	1	1.3	13	India	10	2.1	15	1.228
Czech Rep	1	1.3	13	Netherland	9	1.9	17	1.789
Australia	1	1.3	13	Iran	8	1.7	18	1.483
New Zealand	1	1.3	13	Greece	6	1.3	19	1.746
Sweden	1	1.3	13	New Zealand	6	1.3	19	1.859
Brazil	1	1.3	13	Singapore	6	1.3	19	1.651
Hungary	1	1.3	13	Egypt	5	1.1	22	1.556
South Korea	1	1.3	13	Saudi Arabia	5	1.1	22	1.607
Greece	1	1.3	13	Serbia	5	1.1	22	1.020

(IF: impact factor). Countries publishing DFE research in 1999-2000 and 2009-2010 are displayed in decreasing order according to the number of publications for each time period. The country average of 2010 Impact Factors is mentioned for the 2009-2010 period.

The number of countries publishing DFE literature doubled in one decade, from 24 to 54. The USA published the most at both time points, but its share declined by 10.5% between 1999-2000 and 2009-2010. Over the same period, the European Union (EU)'s share declined a little bit less (by 8.7%.)

A country could belong to the top 10 with only three publications in 1999-2000, whereas 16 publications were needed in 2009-2010. Four countries reached the top 10 for the first time in 2009-2010, and each produced more than 15 publications: Italy (12^{th} in 1999-2000), Brazil (21^{st}), Australia (18^{th}) and South Korea (23^{rd}). They replaced Switzerland, Netherland, Canada and Belgium, which still remained in the new top 20 with more than eight papers each.

In terms of impact factor (IF), the world average (calculated as the average of each country's average) was similar to the average IF of the top 10 countries in 2009-2010 (1.87±1.19 and 1.9±0.3 respectively). Among the top 10, Australia had the highest average IF (2.43) and Turkey the lowest one (1.45), and both published 21 papers.

Of the 27 EU countries, 22 published at least one DFE paper in 2009-2010. The five countries that did not publish were Bulgaria, Estonia, Latvia, Luxembourg, and Slovakia.

The Most Publishing Country Shared 45% of its Authorship with Other Countries (Table 2)

When analyzing the country-to-country collaboration of the top 6 publishing-DFE countries, it appears that USA was the most collaborative country with 45% of its publications, while Brazil only shared 19% of them. China had a mean of 3.22 papers per country collaboration, while Italy shared a total of 7 collaborative papers with 10 countries at the same time. USA was the top 6's favorite collaborative country (27 publications), with exception for the Japanese who preferred China.

Table 2. Publishing profiles of the top-six most prolific countries (and European Union) involved in DFE research for the 2009-2010 period.

Countries/ Territories	*# Papers*	*# International Collaborative Papers*	*# Collaborative Countries*	*Main Collaborative Countries*	*# Papers/ Country*	*Main Targeted Journals*	*# Papers/ Journal*
EU	142	49	21	USA Switzerland Japan	13 9 6	Clinical Oral Implants Research International Journal of Oral & Maxillofacial Implants Dental Materials Journal of Biomechanics	20 10 6 6
USA	104	47	22	China Brazil Germany	13 7 4	Journal of Craniofacial Surgery International Journal of Oral & Maxillofacial Implants Dental Materials Journal of Prosthodontics	9 7 5 5
China	89	29	9	USA Australia Japan	13 6 5	International Journal of Oral & Maxillofacial Implants Journal of Biomechanics Dental Materials Journal of Endodontics	6 6 5 5
Brazil	58	11	7	USA Belgium	7 2	Journal of Craniofacial Surgery International Journal of Oral & Maxillofacial Implants Dental Materials Journal of Prosthodontics	9 7 5 5
Japan	41	12	8	China Netherlands	5 2	Dental Materials Journal International Journal of Oral & Maxillofacial Surgery International Journal of Oral & Maxillofacial Implants International Journal of Prosthodontics Journal of Oral Rehabilitation	8 4 3 3 3
Germany	33	14	10	USA Switzerland Turkey	4 4 3	International Journal of Oral & Maxillofacial Implants Acta Biomaterialia Journal of orofacial orthopedics International Journal of Prosthodontics	6 4 2 2
Italy	25	7	10	USA	3	Clinical Oral Implants Research American Journal of Dentistry Angle Orthodontist Journal of Biomedical Materials Research Part B Journal of Endodontics	5 2 2 2 1

The Mean Impact Factor for DFE Journals Increased by 75% the Last Decade (Table 3)

The mean IF increased by 75% between 1999-2000 and 2009-2010 for the top 10 journals publishing DFE papers (1.19 and 2.08 respectively), and by 165% when considering only the top 3 journals (0.89 and 2.35). The journal IFs were comprised between 0.565 and 1.9 in 1999-2000, and between 0.772 and 3.291 in 2009-2010.

The 3 most publishing journals represented around 45% of the top 10 production at both time-points (21/45 in 1999-2000 and 73/162 in 2009-2010). The number of papers from the 10 most publishing journals increased by 3.6 fold during the decade.

Half of 1999-2000 journals remained in the top 10 in 2009-2010, when considering the "Journal of Biomedical

Materials Research Part A" as a part of the former "Journal of Biomedical Materials Research" since 2003. Six out of the top 10 journals were published in the USA in both periods. The number of journals involved in the DFE literature increased 3.6 fold during the decade (from 40 journals in 1999-2000 to 144 in 2009-2010; data not shown).

Table 3. Top-ten most prolific journals with DFE research papers and their impact factors (IFs) for 1999-2000 and 2009-2010 peri-ods (IF: impact factor).

1999-2000				2009-2010			
Title	**# Papers**	**IF (2000)**	**Web of Science Category**	**Title**	**# Papers**	**IF (2010)**	**Web of Science Category**
Journal of Oral Rehabilitation	9	0.565	Dentistry, Oral Surgery & Medicine	International Journal of Oral & Maxillofacial Implants	35	1.681	Dentistry, Oral Surgery & Medicine
International Journal of Oral & Maxillofacial Implants	6	1.316	Dentistry, Oral Surgery & Medicine	Dental Materials	20	2.920	Dentistry, Oral Surgery & Medicine; Materials Science, Biomaterials
Journal of Prosthetic Dentistry	6	0.787	Dentistry, Oral Surgery & Medicine	Journal of Biomechanics	18	2.463	Biophysics; Engineering, Biomedical
American Journal of Orthodontics and Dentofacial Orthopedics	3	0.757	Dentistry, Oral Surgery & Medicine	American Journal of Orthodontics and Dentofacial Orthopedics	17	1.354	Dentistry, Oral Surgery & Medicine
American Journal of Physical Anthropology	3	1.827	Anthropology; Evolutionary Biology	Clinical Oral Implants Research	13	2.812	Dentistry, Oral Surgery & Medicine; Engineering, Biomedical
Biomaterials	3	1.796	Engineering, Biomedical; Materials Science, Biomaterials	Journal of Craniofacial Surgery	13	0.772	Surgery
Clinical Oral Implants Research	3	1.680	Dentistry, Oral Surgery & Medicine; Engineering, Biomedical	Journal of Endodontics	13	3.291	Dentistry, Oral Surgery & Medicine
International Journal of Prosthodontics	3	1.182	Dentistry, Oral Surgery & Medicine	Dental Materials Journal	11	1.112	Dentistry, Oral Surgery & Medicine; Materials Science, Biomaterials
Journal of Biomedical Materials Research	3	1.900	Engineering, Biomedical; Materials Science, Biomaterials	Journal of Biomedical Materials Research Part A	11	3.044	Engineering, Biomedical; Materials Science, Biomaterials
Journal of Cranio-Maxillofacial Surgery	3	0.636	Dentistry, Oral Surgery & Medicine; Surgery	Journal of Prosthetic Dentistry	11	1.309	Dentistry, Oral Surgery & Medicine
Journal of Materials Science-Materials in Medicine	3	0.621	Engineering, Biomedical; Materials Science, Biomaterials				

Five of the journals that published the largest number of DFE papers in 1999-2000 were referenced in the WoS database as specialized in "Dentistry, Oral Surgery & Medicine" in comparison to four in 2009-2010; in addition, two belonged to another category (*versus* three in 2009-2010). It is noteworthy that the two journals on medical materials have been replaced by two on dental materials.

The most represented articles were "Dentistry, Oral Surgery & Medicine" (59% in 1999-2000, 56% in 2009-2010), "Engineering, Biomedical" (27% and 21% respectively) and "Materials Science" (14% and 17% respectively) [data not shown]. A minority of papers was referenced in 2 categories at the same time.

DISCUSSION

The results of this bibliometric study showed that FE literature in dental research generates increasing interest from scientific authors and publishers around the world. The evidence is that the volume of DFE publications increased exceptionally fast (Fig. **1**), the number of countries involved in authorship doubled the last decade (Table **1**), collaborations are frequent (Table **2**), and the mean impact factor of the top 10-publishing journals rose by 75% (Table **3**).

Finite element analysis in dental research is a promising field. Our first finding, that DFE literature has grown exceptionally fast, is supported by the comparison with the literature from related scientific domains. The number of

publications on DFE increased from 3 in 1990 to 257 in 2010, whereas all scientific publication went through a twofold increase (Fig. **1**). An explanation may be that DFE literature combines both the rising interests in dentistry and in FE analysis. Furthermore, the continuous development of FE

Software and its availability on personal computers has supported the increase of the DFE authors. The second finding, that the number of countries involved in DFE authorship grew substantially from 24 to 54 in one decade (Table **1**), also supports the idea of an increasing community. Nearly half of these countries in 2009-2010 published at least five papers, showing that the country contribution is not accidental or isolated. Furthermore, the fact that the USA, the country that published the most DFE papers, collaborated on 45% of its publications in 2009-2010 confirms that the DFE field is expanding across national frontiers (Table **2**). A hypothesis for this high level of collaboration may be that clinical researchers can ask for help from researchers skilled in DFE who do not necessarily live nearby. Finally, we showed that the impact factor of journals publishing DFE studies has increased the last decade, evidence that DFE studies were likely cited by peers, and consequently of interest for editors and publishers.

United States leadership in DFE productivity may be soon challenged. We observed that USA was the most publishing country of DFE papers, as in all fields of research [6]. However, several lines of evidence support the hypothesis that this leadership may come to an end. First, our finding that USA share of publications was decreasing is consistent

With the global trend described in science and technology [7]. Second, the emergence of South Korea in the top 10 (from 23th in 1999-2000 to 10th in 2009-2010) and the increased leadership of China (including Taiwan, from 6th to 2nd) were also noted in different fields of research [8 - 11]. Indeed these countries are driven by a strong economic growth and invest massively in research competition. Third, we also found that EU share of total publications was greater than the USA's at both time periods. However this observation was also made by Albarran (2010) [12], who interestingly added that USA publications were still more cited than EU's.

Africa remained under represented in 2009-2010, consistently with other bibliometric studies [8, 10, 13]. The only African countries to be reported were Egypt (ranking 22, 5 papers), Algeria and South Africa (ranking 31 ex aequo with 2 papers; Table **1**).

"Dentistry" and "material science" journals support the interest for DFE literature. Our results suggest that journals publishing DFE literature were related with implant biomechanics (such as dental materials, prosthodontics and orthodontics) (Table **3**). The International Journal of Oral & Maxillofacial Implants was the most publishing journal of DFE studies in 2009-2010, with 35 papers (Table **3**) which represented 8% of its publications. This journal was already ranking second in 1999-2000 with 6 papers. Its most cited DFE papers were in 2001 a review article with 7 citations [14] and in 2011 an original research article with 16 citations [15]. In 10 years, its IF increased by an average of 2.5% per year, which is similar to the average rate of 2.6% per year described for all journals listed in the Thomson Scientific Journal Citation Reports (Science and Social Science editions for the years 1994-2005) [16]. This natural IF increase has been shown to be mainly due to the increase of references listings in all papers over the years [16]. An explanation to this stabilized situation may be that articles about dentistry were hardly exportable to journals outside the disciplinary field, limiting the expansion of dental journals through scientific impact metrics [17]. As these indexes tend to determine the quality not only of papers and journals, but researchers as well [18], authors tried to publish outside the strictly dentistry field. This trend led to an IF increase of DFE literature and the diversification of WoS categories (Biophysics; surgery; engineering, biomedical, Table **3**). Interestingly, most of the journals in the 1999-2000 ranking were either considered as "Dentistry" or "Material science". However, a new and promising WoS category of journal emerged in the top 10 ranking of 1999-2000, combining both "Dentistry" and "Materials science" ("Dental Materials" created in 1984 and "Dental Materials Journal" in 1981). These highly specialized journals may contain the new audience of DFE papers.

Dental-related FE papers are not "classic" citations yet. The DFE papers represented 0.22% of the dental literature in 1999-2000, and only 0.72% ten years later. Interestingly, the percentage of papers mentioning "finite element" in their title remain 36%. This could mean that the same proportion of studies were pure FE studies, as opposed to those performing FE analysis among other methods to achieve their demonstration. In studies analysing the top 55 cited-papers in periodontology [19] (2007) and top 100 in endodontics [20] (2011), DFE papers were not yet part of the "classic articles". However in these previously studied journals, some DFE papers can reach more than 30 citations in periodontology [21 - 23] and more than 60 in endodontics [24 - 26]. In a selected panel of orthodontic journals, only one paper [27] (published in 1987) was part of the 2013 top 100 [28]. Even in the implantology and prosthodontics

fields, DFE papers still represent less than 4% of the top 100 (data not shown).

The period covered by this bibliometric study is a limitation. First, the Science Citation Index (SCI) Expanded® has coverage only since 1991 for 70% of the articles of full-length, English-language, author, abstracts, (http://images.webofknowledge.com/WOK45/help/WOS/h_database.html). The 1991 improvement of the coverage was associated with a sudden 2.7 fold increase for dental literature in the WoS database between 1990 and 1991 (data not shown). However, the SCI-Expanded provides complete bibliographical information over 8,500 major international journals across 150 disciplines, dating back to 1900. Second, some journals are referenced later than others, and IF are released six months after the year of publication. As a consequence, we could not analyse accurately publications retrieved from the last couple of years. Third, in order to have bigger numbers of publication, we studied publications retrieved from periods of a couple years. As these represented a lot of manual analyses, we did not compare more than two periods. Anyway, we do believe that our assumptions were reasonable as trends in DFE publications evolved exponentially with predictability (Fig. **1**).

CONCLUSION

In conclusion, the results of this bibliometric study showed that FE literature in dental research generates an increasing interest from authors and publishers around the world. The evidences are that the volume of DFE publications increased exceptionally fast, the number of countries involved in authorship doubled the last decade, collaborations are frequent, and the number of publishing journals increased while the mean impact factor of the top 10 publishing journals arose by 75%. It is hoped that the present study showing the richness, importance, and diversity of DFE research provides a useful description of the scientific literature and will encourage researchers to further advance this field.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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