



REVIEW ARTICLE

# The trends of dental biomaterials research and future directions: A mapping review



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Received 23 May 2020; revised 10 December 2020; accepted 3 January 2021

Available online 14 January 2021

## KEYWORDS

Dental biomaterials; Dental innovations; Analytical techniques; Properties; Regenerative dentistry; Digital dentistry

**Abstract Objective:** This literature research aimed to compare, contrast and quantify the innovations in the most commonly used dental biomaterials.

**Methodology:** Original research articles based on experimental dental biomaterials published between 2007 and 2019 were retrieved and reviewed. A search of electronic databases, PubMed, Scopus, and Web of Science indexed dental/biomaterials journals, has been conducted. The inclusion criteria in this research were: synthesis of experimental dental materials, whereas commercial dental materials, review articles, and clinical trials (case reports) were excluded.

**Results:** It was found that the amount of publications related to dental subgingival implants, computer-aided modeling ceramics, aesthetic restorative materials, adhesives cements, ceramics, bioceramics, endodontic materials, bioactive scaffolds, stem cells, and guided-tissue membranes had increased significantly from 2007. At the same time, the number of publications related to dental cements, silver amalgam, and dental alloys has decreased. For characterization of dental materials it was noted that mechanical properties were tested mostly for restorative materials. On the

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Peer review under responsibility of King Saud University.



other hand, biological properties were most assessed for dental subgingival implants and endodontic materials, however, physical properties predominantly for bioceramics.

**Conclusion:** It is concluded that to meet clinical demands there was more focus on restorative materials that provided better aesthetics, including resin composites, adhesive resin composites (luting cements), zirconia, and other ceramics. The boost in laboratory and animal research related to bioceramics was attributed to their regenerative potential. This current literature study will help growing researchers to consider and judge the direction to which research might be guided in order to plan prospective research projects.

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## 1. Introduction

Dr. E.C. Combe made a survey in 1974 to quantify research abstracts published, and patents issued, regarding dental materials. He was focusing particularly on ceramic, metallic, and polymeric materials between 1907 and 1972 (Combe, 1974). Combe concluded that during this said era the research regarding gypsum products, ceramics, dental cements and investment materials decreased, but perhaps surprisingly, remained constant for metallic materials. Yet, there was growing interest in research of polymeric materials that time. However, the turn of the millennium to 2000 has seen a paradigm shift in the research of biomaterials including dental materials. The shifting balance of biomedical research towards regenerative biomaterials (resorbable) or bioinert materials (biostable) with specific requirements, innovative fabricating techniques of implants, and application of laser in restorative dentistry, calls for functional materials. Such materials could be with tailored physical, mechanical, chemical, and biological characteristics for enhanced adhesion, quicker healing, and fast tissue regeneration. These customized properties are specifically accredited to materials with an increased surface-to-volume ratio (Sun and Zhang, 2012).

A significant rise has been observed in applications of nanotechnology in dentistry and dental tissue engineering. Synthetic nano-hydroxyapatite, bioactive glasses, silver nanoparticles, nano-diamonds, zirconia nanoparticles, and nano-topography of titanium implants for replacing missing teeth (and bone) top the list (Cao et al., 2018; Boutinguiza

et al., 2018). Moreover, a substantial focus has been laid on using nanomaterials in engineering and delivering stem cells for regeneration of dental tissues such as enamel, dentin, cementum, pulp, gingival epithelium, and periodontal ligaments. The use of stem cells has catapulted the research towards polymers, in order to search for a suitable scaffold or delivery method (Bayne, 2005).

Similarly, interdisciplinary approaches are being adopted by researchers to expand the horizon of biomaterials, and maximize their clinical benefits. This is understandable because biomaterials science crosses roads with other biological sciences. Nevertheless, some other examples of interdisciplinary approaches include the relationship of proteomics and dental biomaterials to better deeply understand the biological responses of dental subgingival implant materials (Zhao et al., 2012; Khurshid et al., 2016), molecular biology and its role in biomineralization by materials (Galler et al., 2016) or microbiology to study the antimicrobial effects of materials such as nano-silver particles or quaternary ammonium compounds (Imazato et al., 2014; Jadhav et al., 2016).

The growing desire and demand for aesthetic restorations has led to continuous evolution of dental resin-based composites (resin composites), dentin adhesives, and attempts for dental silver amalgam alternatives. The benefits of preserving natural and intact tooth tissues as much as possible have gained many advocates, which have shifted the paradigm of contemporary dentistry towards minimally invasive (conservative) and adhesive dentistry. Growing interest in implant dentistry focuses the research on ceramic implant materials, their

design and surface treatment chiefly by addition of inorganic or organic phases, to improve their osseointegration (Gaviria et al., 2014; Siddiqi et al., 2017).

A wide array of requirements and standards set out by organizations such as International Organization for Standardization, American Dental Association, and US Food and Drug Administration need to be fulfilled before any biomaterial can be deemed safe and acceptable for clinical use. This is why each new experimental dental biomaterial undergoes vigorous assessment and inspection in which their properties are tested according to those standards. That said, these guidelines are continuously being revised and updated according to new evidence, and experimental materials are tested according to the standards and regulations. Moreover, the Academy of Dental Materials introduced guidelines to help researchers to select suitable test methods (Cesar et al., 2017). The emerging trends in dental materials research are targeted at developing new materials or tailoring the properties of existing materials in order to attain and improve their desirable properties.

The authors share the view that it is timely to quantify the changing trends in dental biomaterials research in order to judge the direction in which research is headed. It is noteworthy that a bibliographic analysis of scientific research in dental biomaterials is a complex process and no specific methodology has been developed that completely fulfils the requirements of researchers (Kelly et al., 2014). In this literature study, the qualitative evaluation of scientific publications of the last decade was performed using various variables of dental biomaterials. This will help the researchers in evaluating the needs of specific materials and their properties to design future research topics. Furthermore, to predict the research trends in the near future, this literature study focuses at quantifying innovations.

## 2. Methods

A search was carried out on PubMed, Scopus, and Web of Science databases to evaluate the trend of articles published in indexed journals on dental biomaterials. The PRISMA guidelines (Moher et al., 2009) were followed wherever possible. The keywords used were “dental materials”, “dental biomaterials”, “dental trend”, “dental research”, and “dentistry”. Additionally, a timeline filter was applied to show only those articles that were published in the last 13 years (from 2007 to 2019). The abstract of each research article was read and articles fulfilling the inclusion criteria were selected. Full texts of papers were obtained from the journals respectively. Before starting the literature search, the authors decided on the following inclusion and exclusion criteria. The inclusion criteria were: (i) only the papers which describe the synthesis (fabrication) of experimental dental biomaterials; (ii) modification of existing commercial materials in order to change the properties of the material; (iii) laboratory testing (*in vitro*), *in vivo*, and *ex vivo* testing; and (iv) full text articles in indexed journals published in English in PubMed/Scopus/Web of Science (2007–19). Whereas, the exclusion criteria were: (i) articles based on commercial products; (ii) systematic, meta-analysis and critical review articles;

(iii) clinical trials and case reports; (iv) comparison of properties of commercial products; (v) new techniques to check previously tested property; (vi) modification of a cavity design; and (vii) testing a new operative procedure by using commercial products.

The title and abstract of all articles identified by the electronic search were read and assessed by three authors (SI, NJ, and MS). The full text articles of all studies based on inclusion criteria were retrieved. After application of the search strategy, two examiners (SI and ASK) reviewed and performed the selection by consensus with the objective of complementing the database searches. References in papers were checked and cross-matched with those from the original search. Where additional references were found which met the inclusion criteria, these were included in the review material. After identifying the eligible studies in the above databases those studies were imported into Endnote X7 software (Thompson Reuters, Philadelphia, PA, USA) to remove duplicates.

The dental materials were categorically classified into major groups including: resin composites, adhesives (dentin primers), dental implants, dental ceramics (porcelain), glass ionomer cements, periodontal membranes, bioceramics, zirconia, CAD/CAM ceramics, dental cements, base metal alloys, denture related materials, bleaching and whitening materials, impression materials, endodontic post systems, amalgam, and obturating materials or root canal sealers. Additionally, scaffolding materials, toothpastes, and dentifrices, materials used for guided bone regeneration *etc.* were grouped under ‘miscellaneous’.

The properties tested for each dental material were also classified broadly into mechanical (compressive strength, tensile strength, shear bond strength, flexural strength, and hardness), physical (optical properties, thermal expansion, differential scanning calorimeter, surface morphology, microstructural analysis, water sorption, rheological properties, dentin permeability, and polymerization shrinkage), chemical (degree of conversion, ion release, thermogravimetric analysis, and chemical spectroscopic analysis), and biological (biocompatibility, remineralization, apatite formation, and biodegradation).

### 2.1. Statistical analysis

The comparative data search of number of published articles and analytical techniques were statistically (independent *t* test) analyzed by using SPSS version 22 (IBM Software, Armonk, NY, USA). The data obtained from subsequent years were compared and contrasted with these results.

## 3. Results

The schematic illustration of searched data is shown in Fig. 1. The search as per keywords showed that 488,273 articles in indexed journals were published during 2007–2019 in the PubMed, Scopus, and Web of Science and they were initially selected. After deleting the duplicates 53,192 articles were included, and among which only 3,662 articles fulfilled all criteria set and the data was collected. Figs. 2 and 3 show comparative researches carried out on different

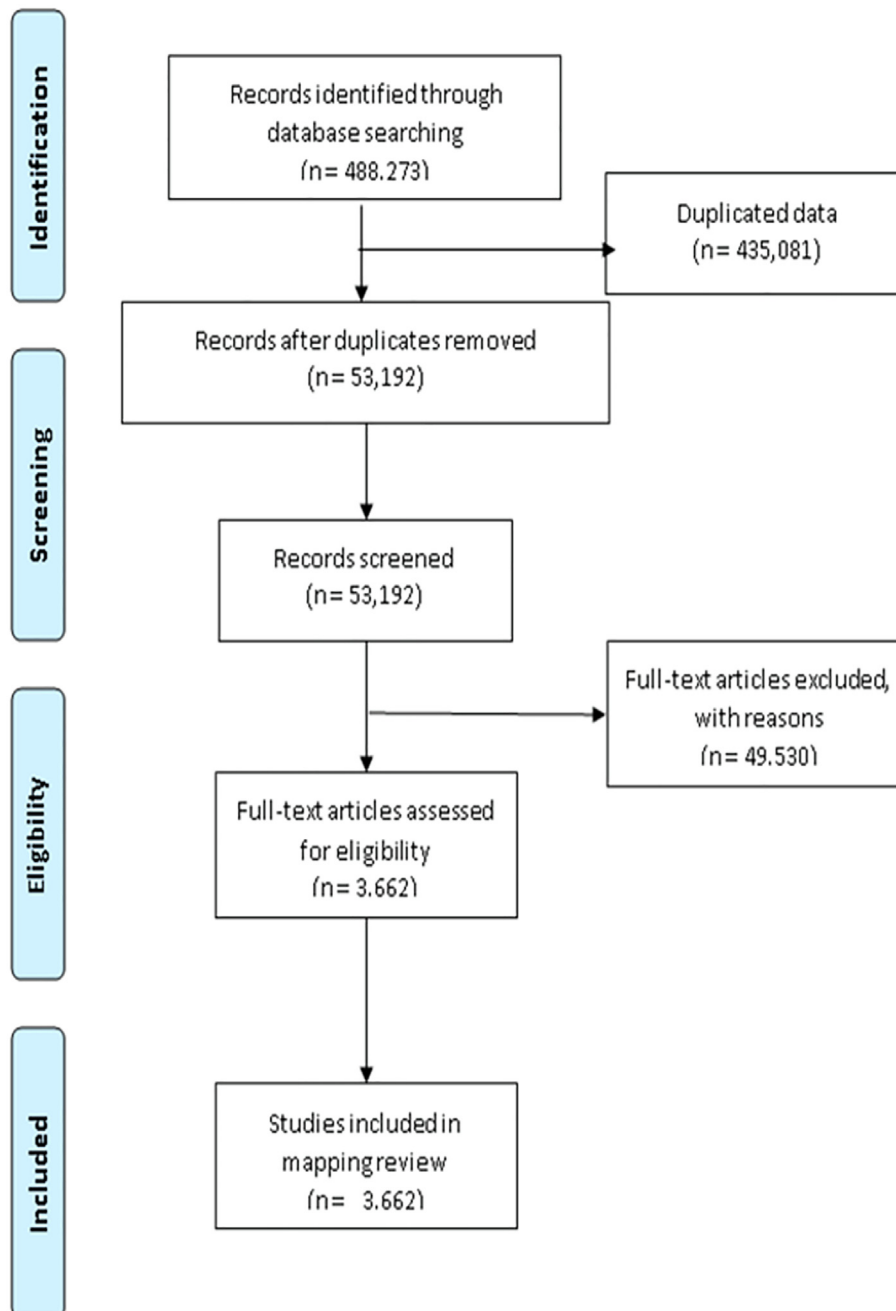


Fig. 1 PRISMA flow diagram showing schematic pattern of study search.

dental materials as a percentage of total number of included articles<sup>1</sup>.

### 3.1. Comparative trend of dental biomaterials research (2012–2019)

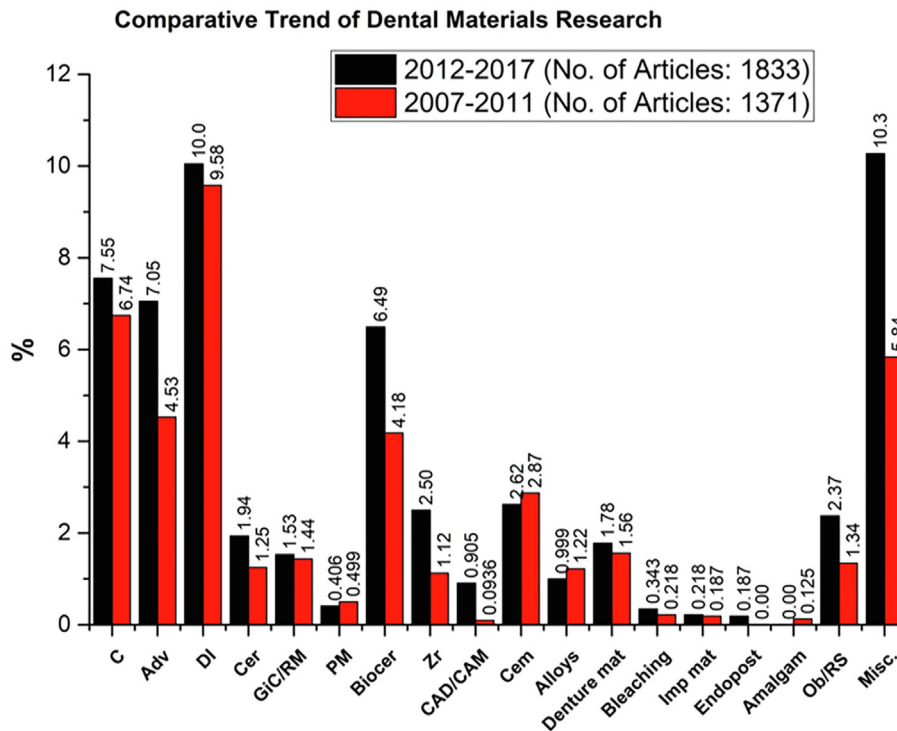
Data analysis obtained showed that in 2018 and 2019, most research in dental materials focused on dental implants, bioce-

ramics, and miscellaneous materials, such as membranes for guided bone regeneration, scaffolds as stem cell carriers, dental implants, bioactive molecules, bioactive scaffolds for regenerative purposes, hydrogels, toothpastes, denture cleaners, and varnishes. This was followed by resin-based composites and alloys. A similar trend was found during 2012–2017 with most research concentrating on bioceramics, followed by miscellaneous materials, resin composites, and dental adhesive cements.

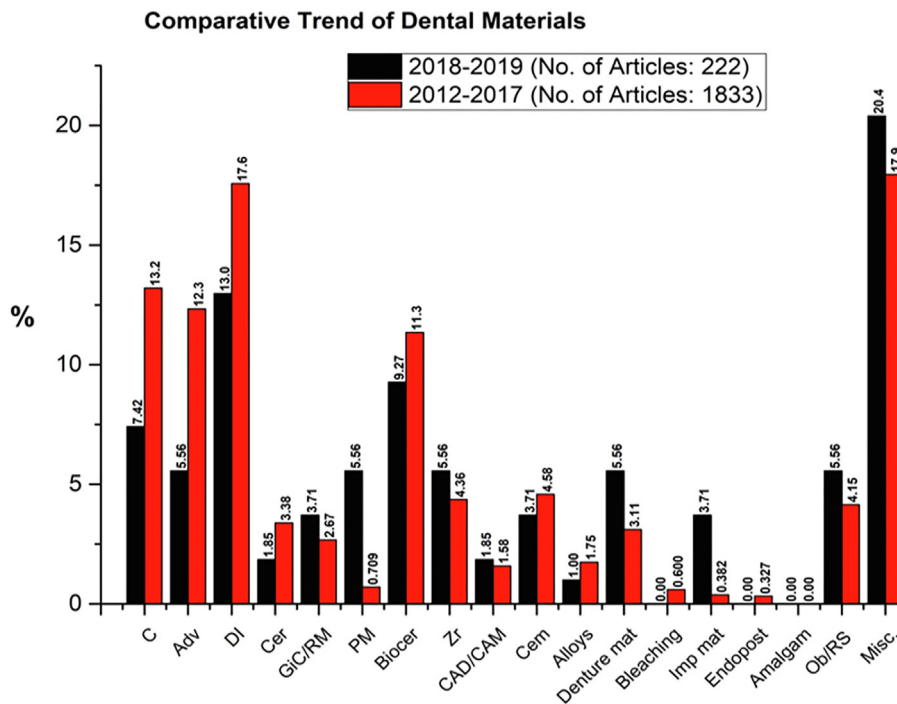
### 3.2. Comparative trends of dental biomaterials research (2007–2011)

On the other hand, during the years 2007–2011, research was more focused on dental implants followed by resin composites

<sup>1</sup> Comp = Resin Composites, Adv = Adhesives, DI = Dental Implants, Ceram = Ceramics, GIC/RM = Glass Ionomer Cements/Resin Modified, PM = Periodontal membrane, Biocer = Bioceramics, Zr = Zirconia, Cem = Cements, Imp Mater = Impression Materials, Ob/RS = Obturating material/Root canal sealers.



**Fig. 2** Comparative trend between 2007–2011 and 2012–2017 of published research articles of different dental materials (description of abbreviations are given in footnote). The comparison is presented in percentages.



**Fig. 3** Comparative trend between 2012–2017 and 2018–2019 of published research articles of different dental materials (description of abbreviations are given in footnote). The comparison is presented in percentages.

and dentin adhesives. It was observed that 2012 onwards, there was a 4.88% increase in research in dental implants. For resin composites, there was a 12.0% increase in research during

2012–2017. A significant increase ( $p \leq 0.05$ ) in research of dental adhesives and miscellaneous materials was observed which doubles in the last 7 years. The research related to use of bio-



**Table 1** Number of articles published during 2007–2019 in representative journals of Dental Biomaterials, Dentistry, and Biomaterials.

Sr. #	Journal Title	TP* (2007–11)	TP (2012–17)	TP (2018–19)
1.	Dental Materials (Elsevier)	999	977	385
2.	Dental Materials Journal (Japanese society of dental materials and devices)	666	544	256
3.	Journal of Dental Research (SAGE Publishers)	1044	967	380
4.	Journal of Dentistry (Elsevier)	890	688	351
5.	The Journal of Adhesive Dentistry (Quintessence Publishing)	255	305	343
6.	Operative Dentistry (Academy of Operative Dentistry)	484	452	193
7.	Acta Biomaterialia (Elsevier)	2834	1679	1207
8.	Journal of Dental Sciences (Elsevier)	201	178	114
9.	Biomaterials (Elsevier)	4182	3812	1121
10.	Journal of Materials Science: Materials in Medicine (Springer)	1373	1449	2589
11.	Journal of Biomedical Materials Research Part A (Wiley)	1834	2309	608
12.	Journal of Biomedical Materials Research Part B (Wiley)	917	1341	634
13.	Journal of Endodontics (Elsevier)	1737	1632	479
14.	Journal of Prosthodontics-Implant Esthetic and Reconstructive Dentistry (Wiley)	551	489	401
15.	British Dental Journal (Nature)	319	266	457
16.	Journal of The American Dental Association (Elsevier)	770	705	194
17.	Brazilian Dental Journal (Scopus)	621	371	171
18.	International Journal of Oral and Maxillofacial Implants (Quintessence)	1104	625	319
19.	Clinical Implant Dentistry and Related Research (Wiley)	743	201	292
20.	Clinical Oral Implant Research (Wiley)	1060	827	297
	<b>Total</b>	<b>22,584</b>	<b>19,817</b>	<b>10,791</b>

ceramics in dental materials has risen significantly by 55.2% collectively in the journals reviewed in the recent years (2012–2019) compared to 2007–2011. On the other hand, a 6.52% increase during 2012–2017 was seen in research related to innovations in glass ionomer cements. In dental ceramics (other than zirconia) there was an initial 55% increase during 2012–2017 which further increases by 2% in the recent two years. The amount of research publications related to zirconia nearly tripled (122%) showing a significant rise ( $p \leq 0.05$ ) in the years from 2012 to 2019 compared to 2007–2011. In addition, a significant increase ( $p \leq 0.05$ ) was seen in the number of articles published on CAD/CAM ceramics.

Even so, there was an increase in discoveries related to endodontic materials by 76.7% during 2012–2017. In contrast, research and findings related to dental metal alloys has seen a reduction compared to 2007–2011. However, not a single article regarding innovations in dental silver amalgam was published in indexed journals during 2012–2019, whereas only four articles were found published between 2007 and 2011.

Table 1 shows the representative number of reviewed articles searched in Dental Biomaterials, Dentistry, and Biomaterials journals. It was also observed that 72% of the articles regarding new experimental resin composites was published in the specific dental materials related journals (Dental Materials and Dental Materials Journal) and the rest 28% in other dental and biomaterials journals. Similarly, 44% of innovations in dentin adhesives was published in dental materials based journals and 12% in specific dental adhesive journals (Journal of Adhesive Dentistry and International Journal of Adhesion and Adhesives). Nevertheless, in the last 6 years there was a significant rise ( $p \leq 0.05$ ) in articles related to novel ceramic materials. It was observed that 35% of the innovations in miscellaneous materials were published in specific dental

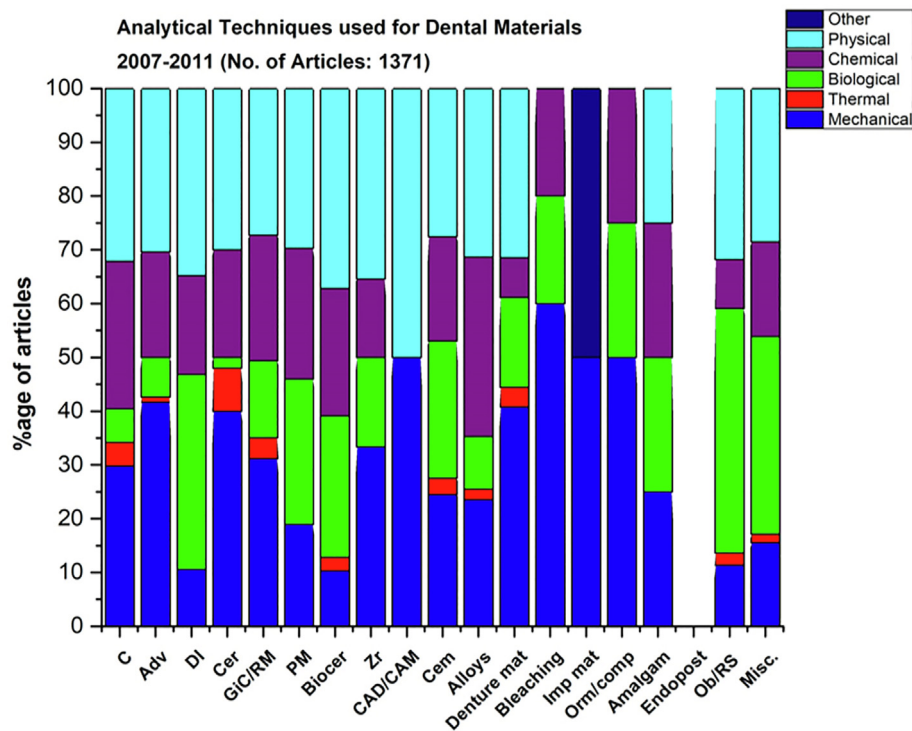
materials related journals (Dental Materials and Dental Materials Journal), while the rest were scattered among the other journals.

### 3.3. Analytical techniques

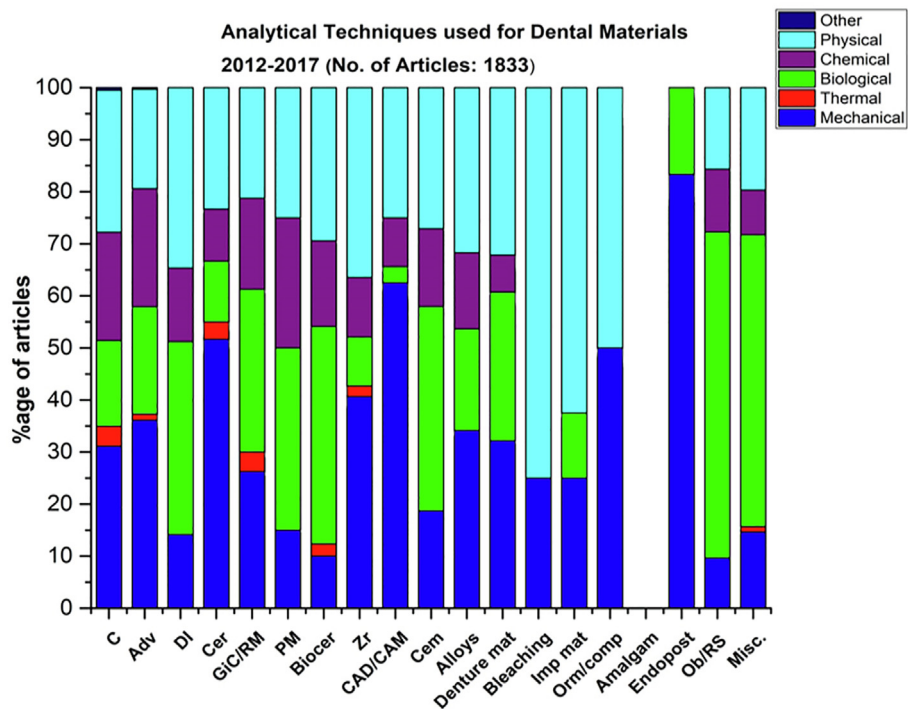
For resin composites, adhesives (dentine primer) and ceramics, their mechanical properties were of the greatest interest (Figs. 4 and 5). Overall, mechanical tests were performed most for each material, 60.7% for adhesives and 54% for resin composites and ceramics. Physical (57.3%) and biological (60.6%) properties of dental implants were tested and evaluated more than the other properties, chemical properties being the second most frequently tested (26.8%). For miscellaneous materials, biological properties (61.5%) were tested the most, followed by physical properties (27.9%). Among these, 46.7% of the cements including glass-ionomer cements had their biological properties tested, followed by physical (49.3%) and mechanical (58.4%). Bioceramics used in dentistry were tested more for their physical (38.2%) and biological (39.7%) properties. Endodontic materials (incl. obturating materials and root canal sealers) underwent biological testing the most, *ie.* 63.7%. Mechanical properties (59%) and physical properties (53%) were compared, contrasted, and tested more for denture materials including denture base materials, denture lining materials, and tissue conditioners.

## 4. Discussion

In the current literature study, three main database search engines were used. PubMed and Scopus are currently the most frequently used resources for information in the biomedical



**Fig. 4** Properties including physical, chemical, mechanical, thermal, biological and others tested for experimental dental materials (description of abbreviations are given in footnote) during 2007–2011.



**Fig. 5** Properties including physical, chemical, mechanical, thermal, biological and others tested for experimental dental materials (description of abbreviations are given in footnote) during 2012–2017.

field. However, PubMed data is limited with bibliographic tags, whereas Web of Science covers complete bibliographic data (Aghaei et al., 2013; Gasparyan et al., 2013). Based on

the data obtained, the research on miscellaneous materials doubled in the last 2 years compared to the period of 2012–2017, during which it also doubled, on the other hand, com-

pared to the period of 2007–2011. This said, it was concluded that research regarding bioactive scaffolds, guided bone and tissue membranes, and stem cells has significantly increased in the last 8 years. This might be attributed to the changing trends in global dental research, which has been targeted at adopting an interdisciplinary approach in order to get materials with more optimized clinical properties and thereby to perform their desired function. Even so, the use of bioceramics in dental materials (especially amorphous calcium phosphate, hydroxyapatite, and bioactive glass) has increased in the last 8 years, owing to their regenerative potential. The interest in their regenerative potential becomes evident by noting that the materials mostly had their physical properties tested which included microscopic analysis of the apatite layers formed and their biological properties tested for analyzing their regenerative potential. Moreover, bioceramics have been incorporated in endodontic materials (Chiang et al., 2016), resin composites (Khalid et al., 2018), dental cements such as GICs (Fuchs et al., 2015), and bone cements (Wang et al., 2016). Bioceramics have been used as injectables (Malik et al., 2020), scaffolds (Khan et al., 2017), carrying growth factors (Lee et al., 2014), and stem cells (Huang et al., 2016) for various dental and craniofacial applications. Similarly, novel innovative bioceramic materials are being engineered with tailored properties for various indications in dental surgery.

On the restorative material front, it was observed that the patients have become more aware and conscious of cosmetic and aesthetic aspects so there is growing demand of aesthetic restorations. Given this, clinicians are losing interest in aesthetically poor amalgam restorations and diverting their attention to more aesthetically pleasing materials like resin composites. To improve the properties of resin composites, certain functional additives have been attempted and added by the researchers to the traditional resin composites, such as hydrophobic polyhedral oligomeric silsesquioxane, a bactericidal component providing dual function of bactericidal activity, and reduction in plasticization effect of water improving the mechanical strength (Burujeny et al., 2017), addition of E-glass glass fibers to further improve the mechanical strength (Syed et al., 2020), addition of bioactive components such as hydroxyapatite (Lung et al., 2016), and bioactive glass (Firzok et al., 2019). It was observed that the mechanical properties of resin composites and dentin adhesives were predominantly under research as researchers have tried to improve the mechanical strength of the materials in majority of the reported innovations. The perhaps radical increase in the research related to zirconia can be attributed to its remarkable potential of mechanical strength and aesthetic properties. This is the reason that mechanical and physical properties of zirconia are mostly investigated and under development (Lung et al., 2012; Matinlinna et al., 2007).

There is a remarkable relationship between the interest in CAD/CAM technique and research carried out on zirconia. The articles about CAD/CAM ceramics significantly increased in during 2012–2017 and nearly doubled in the recent a couple of years and with this rise in the trend of digital dentistry and CAD/CAM technique, research on ceramics, in particular specifically zirconia is on the growing trajectory. The significant increase in the last 8 years in research related to endodontic obturation materials and root canal sealers is a testimony to the ongoing quest for a synthetic (or non-synthetic) material possessing superb clinical properties. Moreover, their biological

properties were investigated as the trend towards using regenerative and bioactive materials in root canals is growing.

An increase in research related to impression materials during last couple of years can be attributed to extensive research on incorporation of antibacterial agents in impression materials (Trivedi et al., 2019). Interestingly, a decrease in research regarding alloys in dentistry was observed during the 2012–2017 period. It can be ascribed to a greater clinical demand in aesthetic restorative materials. This said, dental materials research is now more focused on finding novel, promising alternatives for metallic structures (other than Ti and Ti-alloys). One such alternative involves investigation of polymers such as polyetherether ketone (PEEK), polyether sulfone, and polyvinylidene difluoride as orthodontic wires because of their better aesthetic properties (Maekawa et al., 2015). It was noted that attempts are made to find novel combinations of base metal alloys for better orthodontic appliances, especially orthodontic wires. A new combination of titanium alloys are being investigated due to constant interest of researchers in titanium as a dental biomaterial owing to its highly favorable biological response. For instance, combinations of titanium with copper and niobium for an alloy for dental prosthesis with outstanding mechanical properties (Takahashi et al., 2016).

The trend also shows an increase in research related to subgingival dental implants. Recently, promising results have been published related to use of reinforced E-glass fibers/bioactive glass composites, and PEEK as dental implants (Piitulainen et al., 2017; Schwitalla et al., 2017). Dental implants have undergone biocompatibility, physical and chemical evaluation in order to quantify the innovative effects in surface treatments or novel antibacterial coatings on implant surfaces. Plenty of research is being carried out on developing novel techniques of surface modifications of dental implants which aim at quick and durable osseointegration. Some of the novel methods of surface modifications included antibiotic and nano-silver loaded bone cements, and selective laser melted titanium tantalum niobium zirconium (Ti-Ta-Nb-Zr) alloy (Dziaduszevska et al., 2019), chemical vapor deposition of titanium nitride on cobalt chromium alloys (Song et al., 2020), electrophoretic deposition of ionic-substituted hydroxyapatites (Khan and Awais, 2020), and microwave brazing using gold nano-dots (Tamang et al., 2019).

Bioceramics constitute the second highest category of articles published in indexed journals. The significant use of various bioceramics in dentistry is due to their potential of controlled release of supersaturated ions of calcium and phosphate. This may enhance the longevity of restorations, reduce the chance of bacterial ingestion, and increase the cell proliferation at the tissue-material interface. That said, among bioceramics, the biological properties have been extensively studied in the found journal articles *ie.* in 39.7% of them physical analyses were carried out in 38.2% and chemical analyses in 23%.

Even so, the authors would like to recommend that dental materials researchers adopt an openminded interdisciplinary approach in order to find alternatives for aesthetically poor restorative materials and to overcome the shortcomings in the improvable properties of existing materials. Aesthetics, coupled with the third-generation biomaterials should be in the focus when taking into account the mechanical, biological, and in particular thermal needs of materials to be used in oral and maxillofacial region. The paradigm has made a shift from



inert materials to functionally active with biomimetic approach, which can directly link materials safely with human tissues. Moreover, targeted drug releasing materials and/or the inclusion of antibacterial agents for preventive and therapeutic purposes will be vital. Nevertheless, research based on stem cells in relation to dental material science could be the future and lead it to regenerative medicine. The biological and mechanical properties of bioceramics can be enhanced through ionic substitution. Such ion substitution results in modifying the structure of the crystal lattice which ultimately influences the solubility of these materials. Similarly, the properties of dental resin composites could be enhanced by surface modification of fillers and reinforcing agents. It is expected that the mechanical and physical properties of dental resin composites can further be improved by incorporating ceramics such as alumina, zirconia etc. as reinforcement to increase fracture toughness.

## 5. Conclusion

This literature study demonstrates the current trends in dental biomaterials research. A significant increase was observed in the last 8 years in innovations related to zirconia and scaffolds, guided bone regeneration materials or bioactive molecules. At the same time, a significant decrease of popularity was observed in silver amalgam, non-resinous cements, and alloys. Substantial focus is being laid on aesthetic restorative materials, subgingival dental implants, and certain restorative materials with regenerative potential.

## Ethical Statement

This is a review article and does not need any ethical permission.

## CRedit authorship contribution statement

**Sundus Iftikhar:** Data curation, Formal analysis, Investigation, Writing - original draft. **Nooreen Jahanzeb:** Data curation, Investigation. **Mehvish Saleem:** Data curation, Investigation. **Shafiq ur Rehman:** Data curation, Investigation, Formal analysis. **Jukka Pekka Matinlinna:** Supervision, Writing - review & editing. **Abdul Samad Khan:** Conceptualization, Formal analysis, Validation, Supervision, Writing - review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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