



# A REVIEW ON BIOACTIVE TEETH FILLING MATERIALS

Harini. B<sup>[a]</sup>, Jayalakshmi S<sup>\*[b]</sup>, Balaji Ganesh S<sup>[c]</sup>, Anitha Roy<sup>[d]</sup>

**Article History:** Received: 20.02.2022 Revised: 17.03.2022 Accepted: 16.04.2022

**Abstract:** Materials that are taken from plants or animals and used for replacing and repairing are known as natural bioactive materials. These materials may interfere with the formation of a bond between the material used on the teeth and tissue. Bioactive materials with unique properties are on increased demand in all fields, for long term usage. In place of dental materials also, bioactive dental filling materials are now widely used. Bioactive dental filling materials hold a lot of advantages. Bioactive materials mimic materials such as bioactive dentin, bioactive aggregate, bioactive calcium hydroxide, bioactive glass, bioactive polymers, bioactive metals, bioactive mineral trioxide, aggregate, bioactive ceramics and so on. All bioactive materials do have their own advantages and some disadvantages on the teeth structure. These materials do have some challenges like some materials are ideal for certain patients and vary depending on the restorative needs of the patients, as options and opinions vary with patients. The need for these bioactive materials is mainly because of its demand and reducing the effects of secondary decay once it is replaced or done in the patients. These bioactive materials have more advancements and will change the future dentistry with its emerging technology. This article summarises the concept of bioactivity and compares the various available bioactive materials that are quintessential in every field and showcases the advancements in this topic of dental materials.

**Keywords:** Bioactive materials; advancements; dentin; dental filling materials.

- [a]. Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-77, Tamil Nadu, India
- [b]. Chief Scientist, White Lab- Material Research Centre, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai-77, Tamil Nadu, India
- [c]. Scientist, White Lab- Material Research Centre, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 77, Tamil Nadu, India
- [d]. Associate Professor, Department of Pharmacology, Saveetha Dental college and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai -77, Tamil Nadu, India

**\*Corresponding Author**

**DOI:** 10.31838/ecb/2022.11.02.004

## INTRODUCTION

Bioactive dental filling material has a biological effect on the surrounding tissues. (Hooper and Cassidy, 2006) Desirable bioactive dental filling materials creates a bond with surrounding tooth structure and releases ions to allow the remineralization (Rajendran *et al.*, 2019) of tooth which is lost at the tooth margins and elicits a chemical reaction from the tooth. (Cornara *et al.*, 2017) These bioactive materials last longer when compared to the other dental filling materials. Bioactive materials that are taken from plants or animals used in replacing and repairing are known as natural (R, Rajakeerthi and Ms, 2019) bioactive materials. Bioactive dental filling materials have many physical properties that make them available in every field. (Jesumani *et al.*, 2019). Bioactive restorative materials have long term reduction among all other dental filling materials and are more efficient in treatments where at a times, can be used also as a drug

delivery (Zhao, 2011a, 2011b) (Ramanathan and Solete, 2015) vehicles in conservative endodontic treatments. (Oracz *et al.*, 2019) Drugs or medications are delivered inside the root canal (Kumar and Delphine Priscilla Antony, 2018)) in endodontic treatments. (Manohar and Sharma, 2018) Emphasis on the term disinfection is beneficial rather than cleaning. (*Shape optimal and clean more*, no date)) Medications depending on the bioactive dental filling materials vary for treatment. These restorative materials are commercially available at their union levels. Bioactive dental materials form apatite (Ramesh, Moratti and Dias, 2018) like materials on their surface and help in the remineralisation of the last minerals in the tooth margins and strengthens the tooth structure through fluoride release. (Tanaka *et al.*, 2019) Bioactive materials protect against the dental caries and mostly slow down the secondary tooth decay, which is the most common form of tooth decay. (Khvostenko *et al.*, 2013; Tanaka *et al.*, 2019) Bioactive dental filling materials also reduce matrix metalloproteinase (Teja, Ramesh and Priya, 2018)) by mediating dentin collagen degradation. Secondary caries are the most commonly affected caries and these bioactive materials protect materials against it. To reduce caries effect or to prevent it from getting decayed, mouthwashes and certain toothpaste can be used. Chlorhexidine mouthwashes when compared to mouthwashes prepared from natural products such as neem, tulsi and so on are more effective than the chemical mouthwash used. Chlorhexidine (Noor, S Syed Shihaab and Pradeep, 2016) mouthwashes reduce microorganisms and natural mouthwashes from neem, tulsi (Siddique *et al.*, 2019) and also papaya extract reduce the caries effect in patients. Bioactive restoration has a newer unique mechanism for their adhesion, integration and scaling. (Michou *et al.*, 2018) Bioactive restoration materials stay strong and effective mostly due to these potencies compared to other materials. (Tanaka *et al.*, 2019) Bioactive materials regenerate tissue, promotes tissue healing, repair and maintenance. (Greenspan and Hench, 2013) Bioactive materials combine bioactivity,

biocompatibility and theological properties. (S. R. Jefferies, 2014)(Nandakumar and Nasim, 2018) Bioactive materials are increasing its demand with its recent advancements in dentistry (Ravinthar and Jayalakshmi, 2018) and gaining popularity among the people. Previously our team has a rich experience in working on various research projects across multiple disciplines (Ramesh Kumar *et al.*, 2011; Jain, Kumar and Manjula, 2014; Krishnan, Pandian and Kumar S, 2015; Keerthana and Thenmozhi, 2016; Sivamurthy and Sundari, 2016; Felicita, 2017a, 2017b; Kumar, 2017; Sekar *et al.*, 2019; Johnson *et al.*, 2020). Now the growing trend in this area motivated us to pursue this project.

## BIOACTIVE MATERIALS

**Bioactive Calcium Hydroxide:** Bioactive materials have chemical and physical properties of novel and long standing calcium hydroxide. Calcium hydroxide dissociates generally into calcium and hydroxide ions. (S. R. Jefferies, 2014) The high rate of calcium release and the fast formation of apatite that have a role in calcium silicate biomaterials to induce new dentin bridge formation and clinical healing. These properties contribute a critical role in both. Mechanical and biological properties of glasses (S. Jefferies, 2014) are based on calcium source selection, proposed for hard tissue repair and regeneration. (Greenspan and Hench, 2013).

**Bioactive Mineral Trioxide Aggregate:** Mineral trioxide aggregate is mostly composed of silicate and calcium as major components. The major mixture of bioactive mineral trioxide aggregate is dicalcium silicate, tricalcium silicate. Materials having common characteristics and apatite formation. Mineral trioxide aggregate is a material of choice in vital pulp therapy, apexification (Vidal *et al.*, 2016) and also apexogenesis. Mineral trioxide has few drawbacks of discolouration potential and systemic effects. MTA is used as a pulp capping agent as it induces cytological and functional changes resulting in the formation of fibrodentin. Current articles as said MTA provides a significant clinical advantage over all the traditional cements used (Benetti, 2019) and over different treatment modalities as followed by general dental practitioners. (Jose, P. and Subbaiyan, 2020).

**Bioactive Dentin:** Bioactive dentin is also called and known as „SMART DENTIN“, which is popularly used as replacement material or effective dentin substitute that can be used as a coronal restoration material for indirect pulp capping having similar properties of dentin. (Smith *et al.*, 2016) Biodentin is chiefly composed of highly purified calcium silicate based dental cements. Bioactive dentin has the potential to revolutionize the management of the deep carious cavity in operative dentistry. This material has a positive effect in vital (Sonoyama *et al.*, no date) pulp cell-stimulating (Janani, Palanivelu and Sandhya, 2020) tertiary dentin formation. The efficiency of the diagnostic aids play an important role in treatment plans. Among all other bioactive materials, biodentine has the maximum calcium ion release concentration.

**Bioaggregate:** Bioaggregate has its composition mostly similar to mineral trioxide aggregate and described by its insoluble, radiopaque and primarily composed of calcium hydroxide, calcium silicate and also calcium phosphate. Bioaggregate is used for root end filling materials that shows an excellent biocompatibility (Benetti, 2019) and also has an excellent sealing ability. Bioaggregate exhibits excellent antimicrobial action and a significant induction of bone (Zhao, 2011a) and periodontal regeneration. Bioaggregate are normally produced under controlled pressure, which results in fine and pure white hydraulic cement like powder. Studies have shown that bioaggregate promotes a better adhesion, migration and attachments. (Michou *et al.*, 2018)

**Bioactive Ceramics:** Bioactive ceramics are materials that bond directly with bone without having any fibrillar connective tissue between them. Bioactive ceramics increases the need for bone repair and helps in bonding with bone. (Tirapelli *et al.*, 2011) Bioactive dentin replaces the missing tooth volume and possesses a therapeutic function. Bioactive ceramic forms chemical interfacial bonds with tissue. Bioactive ceramics have a higher stiffness than polymers, inducing the osteogenic stem cell differentiation. (James, 1995) Bioceramics increases its demand due to the increasing need for bone repair due to the prevalence of osteoporosis in the aged population .

**Bioactive Composite:** Bioactive composites help in remineralisation (Ramesh, Moratti and Dias, 2018) and have antibacterial characterisation and inhibits the caries activity. These two factors enable bioactive composites to have caries preventive effects. Bioactive composites replace missing tooth volume and possess many functions. (Iannazzo *et al.*, 2017) Bioactive composites promise in reversing lesions and thereby inhibiting the caries activity. Bioactive composites (Hussainy *et al.*, 2018) were introduced and developed as an aesthetic alternative to dental amalgams which are very widely used in dentistry and intended for anterior teeth restoration. (Tanaka *et al.*, 2019) The main advantage of this material is its capability of regenerating the dental hard tissues, reducing dentin hypersensitivity, postoperative pain and sensitivity (Ramamoorthi, Nivedhitha and Divyanand, 2015) and mainly inhibiting bacterial growth. Our institution is passionate about high quality evidence based research and has excelled in various fields (Pc, Marimuthu and Devadoss, 2018; Ramesh *et al.*, 2018; Ezhilarasan, Apoorva and Ashok Vardhan, 2019; Ramadurai *et al.*, 2019; Sridharan *et al.*, 2019; Vijayashree Priyadharsini, 2019; Mathew *et al.*, 2020). We hope this study adds to this rich legacy.

## CONCLUSION

Bioactive dental filling materials are rapidly growing and gaining popularity among the newer generations. Bioactive with its unique properties and advantages in all fields, increases its demand on long term usage. Bioactive dental filling materials play a major role in reducing the risk and the extent of secondary caries most commonly in the patients. Bioactive materials also have hydrophilic formation, bond between tissue of the tooth structure and the materials. Bioactive materials are ideal for some patients as it varies depending on the patients restorative need and have various opinions and limitations in the treatments. Bioactive will have more demanding future needs with its advancing properties in dentistry especially in the field of dental materials. Bioactive dental filling materials in restorations have newer mechanisms for adhesion, integration and sealing has a strong effective potency. Bioactive dental filling

materials have bioactive ceramics, bioaggregate, bioactive dentin, bioactive calcium hydroxide, bioactive mineral trioxide aggregate, bioactive polymers, bioactive glass and so on with their uniqueness of properties on bonding ability with the tooth structure, remineralising ability by release of calcium, and also reduces the extent of secondary caries in the patient. Bioactive materials have close resemblance with natural tooth in many ways and will change the future dentistry with all its evolving advancements in all fields.

## REFERENCES

- i. Benetti, F. (2019) *Bioactive Materials in Dentistry: Remineralization and Biomineralization*. Nova Science Publishers. Available at: [https://books.google.com/books/about/Bioactive\\_Materials\\_in\\_Dentistry.html?hl=&id=5b0-xAECAAJ](https://books.google.com/books/about/Bioactive_Materials_in_Dentistry.html?hl=&id=5b0-xAECAAJ).
- ii. Cornara, L. *et al.* (2017) 'Therapeutic Properties of Bioactive Compounds from Different Honeybee Products', *Frontiers in pharmacology*, 8, p. 412. doi:10.3389/fphar.2017.00412.
- iii. Ezhilarasan, D., Apoorva, V.S. and Ashok Vardhan, N. (2019) 'Syzygium cumini extract induced reactive oxygen species-mediated apoptosis in human oral squamous carcinoma cells', *Journal of oral pathology & medicine: official publication of the International Association of Oral Pathologists and the American Academy of Oral Pathology*, 48(2), pp. 115–121. doi:10.1111/jop.12806.
- iv. Felicita, A.S. (2017a) 'Orthodontic management of a dilacerated central incisor and partially impacted canine with unilateral extraction - A case report', *The Saudi dental journal*, 29(4), pp. 185–193. doi:10.1016/j.sdentj.2017.04.001.
- v. Felicita, A.S. (2017b) 'Quantification of intrusive/retraction force and moment generated during en-masse retraction of maxillary anterior teeth using mini-implants: A conceptual approach', *Dental press journal of orthodontics*, 22(5), pp. 47–55. doi:10.1590/2177-6709.22.5.047-055.oar.
- vi. Greenspan, D.C. and Hench, L.L. (2013) 'BIOACTIVE GLASS FOR TOOTH REMINERALIZATION AND PAIN DESENTIZATION', *An Introduction to Bioceramics*, pp. 455–462. doi:10.1142/9781908977168\_0031.
- vii. Hooper, L. and Cassidy, A. (2006) 'A review of the health care potential of bioactive compounds', *Journal of the Science of Food and Agriculture*, pp. 1805–1813. doi:10.1002/jsfa.2599.
- viii. Hussainy, S.N. *et al.* (2018) 'Clinical performance of resin-modified glass ionomer cement, flowable composite, and polyacid-modified resin composite in noncarious cervical lesions: One-year follow-up', *Journal of conservative dentistry: JCD*, 21(5), pp. 510–515. doi:10.4103/JCD.JCD\_51\_18.
- ix. Iannazzo, D. *et al.* (2017) 'Hybrid ceramic/polymer composites for bone tissue regeneration', *Hybrid Polymer Composite Materials*, pp. 125–155. doi:10.1016/b978-0-08-100789-1.00006-x.
- x. Jain, R.K., Kumar, S.P. and Manjula, W.S. (2014) 'Comparison of intrusion effects on maxillary incisors among mini implant anchorage, j-hook headgear and utility arch', *Journal of clinical and diagnostic research: JCDR*, 8(7), pp. ZC21–4. doi:10.7860/JCDR/2014/8339.4554.
- xi. James, P.F. (1995) 'Glass ceramics: new compositions and uses', *Journal of Non-Crystalline Solids*, pp. 1–15. doi:10.1016/0022-3093(94)00515-x.
- xii. Janani, K., Palanivelu, A. and Sandhya, R. (2020) 'Diagnostic accuracy of dental pulse oximeter with customized sensor holder, thermal test and electric pulp test for the evaluation of pulp vitality - An in vivo study', *Brazilian Dental Science*. doi:10.14295/bds.2020.v23i1.1805.
- xiii. Jefferies, S. (2014) 'Bioactive and Biomimetic Restorative Materials: A Comprehensive Review. Part II', *Journal of Esthetic and Restorative Dentistry*, pp. 27–39. doi:10.1111/jerd.12066.
- xiv. Jefferies, S.R. (2014) 'Bioactive and Biomimetic Restorative Materials: A Comprehensive Review. Part I', *Journal of Esthetic and Restorative Dentistry*, pp. 14–26. doi:10.1111/jerd.12069.
- xv. Jesumani, V. *et al.* (2019) 'Potential Use of Seaweed Bioactive Compounds in Skincare—A Review', *Marine Drugs*, p. 688. doi:10.3390/md17120688.
- xvi. Johnson, J. *et al.* (2020) 'Computational identification of MiRNA-7110 from pulmonary arterial hypertension (PAH) ESTs: a new microRNA that links diabetes and PAH', *Hypertension research: official journal of the Japanese Society of Hypertension*, 43(4), pp. 360–362. doi:10.1038/s41440-019-0369-5.
- xvii. Jose, J., P., A. and Subbaiyan, H. (2020) 'Different Treatment Modalities followed by Dental Practitioners for Ellis Class 2 Fracture – A Questionnaire-based Survey', *The Open Dentistry Journal*, pp. 59–65. doi:10.2174/1874210602014010059.
- xviii. Keerthana, B. and Thenmozhi, M.S. (2016) 'Occurrence of foramen of huschke and its clinical significance', *Research Journal of Pharmacy and Technology*, 9(11), pp. 1835–1836. Available at: <https://www.indianjournals.com/ijor.aspx?target=ijor:rjpt&volume=9&issue=11&article=002>.
- xix. Khvostenko, D. *et al.* (2013) 'Mechanical performance of novel bioactive glass containing dental restorative composites', *Dental Materials*, pp. 1139–1148. doi:10.1016/j.dental.2013.08.207.
- xx. Krishnan, S., Pandian, S. and Kumar S, A. (2015) 'Effect of bisphosphonates on orthodontic tooth movement-an update', *Journal of clinical and diagnostic research: JCDR*, 9(4), pp. ZE01–5. doi:10.7860/JCDR/2015/11162.5769.
- xxi. Kumar, D. and Delphine Priscilla Antony, S. (2018) 'Calcified Canal and Negotiation-A Review', *Research Journal of Pharmacy and Technology*, p. 3727. doi:10.5958/0974-360x.2018.00683.2.
- xxii. Kumar, S. (2017) 'The emerging role of botulinum toxin in the treatment of orofacial disorders: Literature update', *Asian journal of pharmaceutical and clinical research*, 10(9), p. 21. doi:10.22159/ajpcr.2017.v10i9.16914.
- xxiii. Manohar, M. and Sharma, S. (2018) 'A survey of the knowledge, attitude, and awareness about the principal choice of intracanal medicaments among the general dental practitioners and nonendodontic specialists', *Indian Journal of Dental Research*, p. 716. doi:10.4103/ijdr.ijdr\_716\_16.
- xxiv. Mathew, M.G. *et al.* (2020) 'Evaluation of adhesion of Streptococcus mutans, plaque accumulation on zirconia and stainless steel crowns, and surrounding gingival inflammation in primary ...', *Clinical oral investigations* [Preprint]. Available at: <https://link.springer.com/article/10.1007/s00784-020-03204-9>.
- xxv. Michou, S. *et al.* (2018) 'Adhesion and marginal integrity of bioactive restorative materials', *Dental Materials*, p.



- e11. doi:10.1016/j.dental.2018.08.024. xxxviii.
- xxvi. Nandakumar, M. and Nasim, I. (2018) 'Comparative evaluation of grape seed and cranberry extracts in preventing enamel erosion: An optical emission spectrometric analysis', *Journal of conservative dentistry: JCD*, 21(5), pp. 516–520. doi:10.4103/JCD.JCD\_110\_18. xxxix.
- xxvii. Noor, S.S.S.E., S Syed Shihaab and Pradeep (2016) 'Chlorhexidine: Its properties and effects', *Research Journal of Pharmacy and Technology*, p. 1755. doi:10.5958/0974-360x.2016.00353.x. xl.
- xxviii. Oracz, J. *et al.* (2019) 'Bioavailability and metabolism of selected cocoa bioactive compounds: A comprehensive review', *Critical Reviews in Food Science and Nutrition*, pp. 1–39. doi:10.1080/10408398.2019.1619160. xli.
- xxix. Pc, J., Marimuthu, T. and Devadoss, P. (2018) 'Prevalence and measurement of anterior loop of the mandibular canal using CBCT: A cross sectional study', *Clinical implant dentistry and related research* [Preprint]. Available at: <https://europepmc.org/article/med/29624863>. xlii.
- xxx. Rajendran, R. *et al.* (2019) 'Comparative Evaluation of Remineralizing Potential of a Paste Containing Bioactive Glass and a Topical Cream Containing Casein Phosphopeptide-Amorphous Calcium Phosphate: An in Vitro Study', *Pesquisa Brasileira em Odontopediatria e Clínica Integrada*, pp. 1–10. doi:10.4034/pboci.2019.191.61. xliii.
- xxxi. Ramadurai, N. *et al.* (2019) 'Effectiveness of 2% Articaine as an anesthetic agent in children: randomized controlled trial', *Clinical oral investigations*, 23(9), pp. 3543–3550. doi:10.1007/s00784-018-2775-5. xliv.
- xxxii. Ramamoorthi, S., Nivedhitha, M.S. and Divyanand, M.J. (2015) 'Comparative evaluation of postoperative pain after using endodontic needle and EndoActivator during root canal irrigation: A randomised controlled trial', *Australian endodontic journal: the journal of the Australian Society of Endodontology Inc*, 41(2), pp. 78–87. doi:10.1111/aej.12076. xlv.
- xxxiii. Ramanathan, S. and Solete, P. (2015) 'Cone-beam Computed Tomography Evaluation of Root Canal Preparation using Various Rotary Instruments: An in vitro Study', *The Journal of Contemporary Dental Practice*, pp. 869–872. doi:10.5005/jp-journals-10024-1773. xlvii.
- xxxiv. Ramesh, A. *et al.* (2018) 'Comparative estimation of sulfiredoxin levels between chronic periodontitis and healthy patients - A case-control study', *Journal of periodontology*, 89(10), pp. 1241–1248. doi:10.1002/JPER.17-0445. xlviii.
- xxxv. Ramesh Kumar, K.R. *et al.* (2011) 'Depth of resin penetration into enamel with 3 types of enamel conditioning methods: a confocal microscopic study', *American journal of orthodontics and dentofacial orthopedics: official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics*, 140(4), pp. 479–485. doi:10.1016/j.ajodo.2010.10.022. xlix.
- xxxvi. Ramesh, N., Moratti, S.C. and Dias, G.J. (2018) 'Hydroxyapatite-polymer biocomposites for bone regeneration: A review of current trends', *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, pp. 2046–2057. doi:10.1002/jbm.b.33950. l.
- xxxvii. Ravinthar, K. and Jayalakshmi (2018) 'Recent Advancements in Laminates and Veneers in Dentistry', *Research Journal of Pharmacy and Technology*, p. 785. doi:10.5958/0974-360x.2018.00148.8. li.
- R, R., Rajakeerthi, R. and Ms, N. (2019) 'Natural Product as the Storage medium for an avulsed tooth – A Systematic Review', *Cumhuriyet Dental Journal*, pp. 249–256. doi:10.7126/cumudj.525182. lii.
- Sekar, D. *et al.* (2019) 'Methylation-dependent circulating microRNA 510 in preeclampsia patients', *Hypertension research: official journal of the Japanese Society of Hypertension*, 42(10), pp. 1647–1648. doi:10.1038/s41440-019-0269-8. liii.
- Shape optimal and clean more* (no date) *Paperpile*. Available at: <https://paperpile.com/app/p/b0010d04-60b8-072c-b66f-03d831d07c22> (Accessed: 6 June 2020). liii.
- Siddique, R. *et al.* (2019) 'Qualitative and quantitative analysis of precipitate formation following interaction of chlorhexidine with sodium hypochlorite, neem, and tulsi', *Journal of conservative dentistry: JCD*, 22(1), pp. 40–47. doi:10.4103/JCD.JCD\_284\_18. liii.
- Sivamurthy, G. and Sundari, S. (2016) 'Stress distribution patterns at mini-implant site during retraction and intrusion—a three-dimensional finite element study', *Progress in orthodontics*, 17(1), pp. 1–11. doi:10.1186/s40510-016-0117-1. liii.
- Smith, A.J. *et al.* (2016) 'Exploiting the Bioactive Properties of the Dentin-Pulp Complex in Regenerative Endodontics', *Journal of Endodontics*, pp. 47–56. doi:10.1016/j.joen.2015.10.019. liii.
- Sonoyama, W. *et al.* (no date) 'Multipotent Stem Cells in Dental Pulp', *Culture of Human Stem Cells*, pp. 187–206. doi:10.1002/9780470167526.ch8. liii.
- Sridharan, G. *et al.* (2019) 'Evaluation of salivary metabolomics in oral leukoplakia and oral squamous cell carcinoma', *Journal of oral pathology & medicine: official publication of the International Association of Oral Pathologists and the American Academy of Oral Pathology*, 48(4), pp. 299–306. doi:10.1111/jop.12835. liii.
- Tanaka, C.B. *et al.* (2019) 'Mechanical and antimicrobial properties of novel bioactive dental restorative composites', *Dental Materials*, p. e49. doi:10.1016/j.dental.2019.08.097. liii.
- Teja, K.V., Ramesh, S. and Priya, V. (2018) 'Regulation of matrix metalloproteinase-3 gene expression in inflammation: A molecular study', *Journal of conservative dentistry: JCD*, 21(6), pp. 592–596. doi:10.4103/JCD.JCD\_154\_18. liii.
- Tirapelli, C. *et al.* (2011) 'The effect of a novel crystallised bioactive glass-ceramic powder on dentine hypersensitivity: a long-term clinical study', *Journal of Oral Rehabilitation*, pp. 253–262. doi:10.1111/j.1365-2842.2010.02157.x. liii.
- Vidal, K. *et al.* (2016) 'Apical Closure in Apexification: A Review and Case Report of Apexification Treatment of an Immature Permanent Tooth with Biodentine', *Journal of Endodontics*, pp. 730–734. doi:10.1016/j.joen.2016.02.007. liii.
- Vijayashree Priyadharsini, J. (2019) 'In silico validation of the non-antibiotic drugs acetaminophen and ibuprofen as antibacterial agents against red complex pathogens', *Journal of periodontology*, 90(12), pp. 1441–1448. doi:10.1002/JPER.18-0673. liii.
- Zhao, X. (2011a) 'Antibacterial bioactive materials', *Bioactive Materials in Medicine*, pp. 97–123. doi:10.1533/9780857092939.2.97. liii.
- Zhao, X. (2011b) 'Bioactive materials in drug delivery systems', *Bioactive Materials in Medicine*, pp. 247–265. doi:10.1533/9780857092939.2.247. liii.