BÖLÜM 7

DİŞ HEKİMLİĞİNDE BİYOAKTİF MATERYALLER: GEÇMİŞTEN GÜNÜMÜZE VE GELECEĞE

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GİRİŞ

Restoratif diş hekimliğinin odak noktalarından biri de dünya genelinde en sık karşılaşılan kronik lezyonlardan biri olan diş çürüğünün tedavisidir (1, 2). Uzun yıllar boyunca, bu alanda inert (pasif) özellik gösteren restoratif teknikler uygulanmıştır. Örneğin, amalgam ve klasik rezin kompozit restorasyonlar bu yaklaşımın başlıca örnekleridir. Bu geleneksel yaklaşımın temel prensibi; patolojik olarak bozulmuş dokunun uzaklaştırılması ve yerine mümkün olduğunca inert, biyouyumlu ve mevcut diş dokusuna benzer fiziksel özelliklere sahip materyallerin yerleştirilmesidir. Ancak, klasik yöntemlerin en önemli sınırlılığı; diş sert dokularının zaman içerisinde dinamik yapısal değişiklikler göstermesine karşın, restoratif materyallerin bu biyolojik değişimlere uyum sağlayamamasıdır (3, 4). İşte tam bu noktada, bilim insanları farklı bir kavramsal yaklaşım geliştirmiştir: **biyoaktif restoratif materyaller**. Biyoaktif materyaller, yalnızca eksik dokuyu yerine koymakla kalmayıp, aynı zamanda diş dokuları ile biyolojik etkileşim kurarak terapötik ve rejeneratif etkiler göstermeyi hedeflemektedir (5, 6).

Günümüzde çok sayıda biyoaktif dental materyal geliştirilmekte olup, bu materyaller üzerinde kapsamlı araştırmalar yürütülmektedir. Bu materyallere örnek olarak; biyoaktif camlar, cam iyonomer simanlar (CİS) ve bunların türevleri [örneğin; rezin modifiye cam iyonomer simanlar (RMCİS), klorheksidin (CHX) içerikli CİS'ler, gümüş katkılı CİS'ler, giomerler vb.], kalsiyum silikat bazlı materyal-

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DOI: 10.37609/akya.3816.c748

Tablo 1. Çeşitli karyojenik bakteri türleri için polimerize olmamış MDPB'nin minimum bakterisidal konsantrasyon (MCB) değerleri (μg/mL)	
Bakteri Türü	**Minimum Bakterisidal Konsantrasyon (μg/mL)**
Streptococcus mutans	62.5- 125
Streptococcus sobrinus SL-1	62.5
Streptococcus sanguinis NCTC7863	31.3
Streptococcus salivarius NCTC8618	31.3
Lactobacillus plantarum ATCC14917	15.6
Lactobacillus fermentum ATCC14931	15.6
Propionibacterium acnes ATCC6919	62.5
Bifidobacterium bifidum ATCC29521	62.5
Peptostreptococcus asaccharolyticus ATCC14963	31.3

KAYNAKLAR

1. Gürses M, Ünlü N. Okluzal Çürük Teşhis Yöntemlerine Güncel Bakış. Selcuk Dental Journal. 2017;4(3):153–161.
2. Selwitz RH, Ismail AI, Pitts NB. Dental caries. The Lancet. 2007;369(9555):51–59.
3. Bharti R, Wadhwani KK, Tikku AP, et al. Dental amalgam: An update. Journal of Conservative Dentistry and Endodontics. 2010;13(4):204–208.
4. Ferracane JL. A historical perspective on dental composite restorative materials. Journal of Functional Biomaterials. 2024;15(7):173.
5. Hench LL. An Introduction to Bioceramics. 2nd ed. Singapore: World Scientific; 1993. p.7–8.
6. Negut I, Ristoscu C. Bioactive glasses for soft and hard tissue healing applications—a short review. Applied Sciences. 2023;13(10):6151.
7. Jefferies SR. Bioactive and biomimetic restorative materials: a comprehensive review. Part I. Journal of Esthetic and Restorative Dentistry. 2014;26(1):14–26.
8. Mehta AB, Kumari V, Jose R, et al. Remineralization potential of bioactive glass and casein phosphopeptide-amorphous calcium phosphate on initial carious lesion: an in-vitro pH-cycling study. Journal of Conservative Dentistry and Endodontics. 2014;17(1):3–7.
9. Cakan EF, Eren MM, Günal Ş. Restoratif diş hekimliğinde biyoaktif materyaller. Turkiye Klinikleri Restorative Dentistry-Special Topics. 2018;4(1):46–52.
10. Imazato S, Torii M, Tsuchitani Y, McCabe JF, Russell RRB. Incorporation of bacterial inhibitor into resin composite. Journal of Dental Research. 1994;73(8):1437–1443.
11. Kurtoğlu C. Geleneksel ve adeziv dental simanlar hakkında bir derleme çalışması. Atatürk Üniversitesi Diş Hekimliği Fakültesi Dergisi. 2012;2012(2):205–216.
12. Jefferies SR, Fuller AE, Boston DW. Preliminary evidence that bioactive cements occlude artificial marginal gaps. Journal of Esthetic and Restorative Dentistry. 2015;27(3):155–166.
13. Zhou W, Qiao Z, Nazarzadeh Zare E, et al. 4D-printed dynamic materials in biomedical applications: chemistry, challenges, and their future perspectives in the clinical sector. Journal of Medicinal Chemistry. 2020;63(15):8003–8024.
14. Ma N. Fibroblast growth factor-2. International Journal of Biochemistry & Cell Biology. 2000;32:115–120.
15. Shah P, Aghazadeh M, Rajasingh S, et al. Stem cells in regenerative dentistry: Current unders-

tanding and future directions. Journal of Oral Biosciences. 2024;66(2):288–299.
16. Hendee WR, Chien S, Maynard CD, Dean DJ. The National Institute of Biomedical Imaging and Bioengineering: history, status, and potential impact. Annals of Biomedical Engineering. 2002;30(1):2–10.
17. Yun J, Burrow MF, Matinlinna JP, Wang Y, Tsoi JKH. A narrative review of bioactive glass-loaded dental resin composites. Journal of Functional Biomaterials. 2022;13(4):208.
18. Williams DF. On the nature of biomaterials. Biomaterials. 2009;30(30):5897–5909.
19. Marchi J (ed.). Biocompatible Glasses: From Bone Regeneration to Cancer Treatment. Vol. 53. Cham: Springer; 2016. p.3.
20. Ratner BD, Bryant SJ. Biomaterials: where we have been and where we are going. Annual Review of Biomedical Engineering. 2004;6(1):41–75.
21. Hench LL. Biomaterials Science. Science. 1980;208(4446):826–831.
22. Hench LL, Thompson I. Twenty-first century challenges for biomaterials. Journal of the Royal Society Interface. 2010;7(suppl_4):S379–S391.
23. Sheikh Z, Javaid MA, Hamdan N, Hashmi R. Bone regeneration using bone morphogenetic proteins and various biomaterial carriers. Materials. 2015;8(4):1778–1816.
24. Wang Z, Wang Z, Lu WW, et al. Novel biomaterial strategies for controlled growth factor delivery for biomedical applications. NPG Asia Materials. 2017;9(10):e435.
25. Holzapfel BM, Reichert JC, Schantz JT, et al. How smart do biomaterials need to be? A translational science and clinical point of view. Advanced Drug Delivery Reviews. 2013;65(4):581–603.
26. Shin H, Jo S, Mikos AG. Biomimetic materials for tissue engineering. Biomaterials. 2003;24(24):4353–4364.
27. Polini A, Pisignano D, Parodi M, Quarto R, Scaglione S. Osteoinduction of human mesenchymal stem cells by bioactive composite scaffolds without supplemental osteogenic growth factors. PLoS ONE. 2011;6(10):e26211.
28. Hench LL, Splinter RJ, Allen WC, Greenlee TK. Bonding mechanisms at the interface of ceramic prosthetic materials. Journal of Biomedical Materials Research. 1971;5(6):117–141.
29. Cao W, Hench LL. Bioactive materials. Ceramics International. 1996;22(6):493–507.
30. Karageorgiou V, Kaplan D. Porosity of 3D biomaterial scaffolds and osteogenesis. Biomaterials. 2005;26(27):5474–5491.
31. Noskovicova N, Hinz B, Pakshir P. Implant fibrosis and the underappreciated role of myofibroblasts in the foreign body reaction. Cells. 2021;10(7):1794.
32. Sergi R, Bellucci D, Cannillo V. A comprehensive review of bioactive glass coatings: State of the art, challenges and future perspectives. Coatings. 2020;10(8):757.
33. Islam MT, Felfel RM, Abou Neel EA, et al. Bioactive calcium phosphate–based glasses and ceramics and their biomedical applications: A review. Journal of Tissue Engineering. 2017;8:2041731417719170.
34. Damerau JM, Bierbaum S, Wiedemeier D, et al. A systematic review on the effect of inorganic surface coatings in large animal models and meta-analysis on tricalcium phosphate and hydroxyapatite on periimplant bone formation. Journal of Biomedical Materials Research Part B: Applied Biomaterials. 2022;110(1):157–175.
35. Sarna-Boś K, Boguta P, Skic K, et al. Physicochemical properties and surface characteristics of ground human teeth. Molecules. 2022;27(18):5852.
36. Kobayashi M. The effect of material surface microstructure on the enhancement of bone-bonding ability of a hydroxyapatite-implant by low-intensity pulsed ultrasound (LIPUS). Materials Sciences and Applications. 2021;12(1):42.
37. Bagambisa FB, Joos U, Schilli W. Mechanisms and structure of the bond between bone and hydroxyapatite ceramics. Journal of Biomedical Materials Research. 1993;27(8):1047–1055.
38. Kaimonov MR, Safronova TV. Materials in the Na_2O–CaO–SiO_2–P_2O_5 system for medical applications. Materials. 2023;16(17):5981.
39. Jones JR. Review of bioactive glass: from Hench to hybrids. Acta Biomaterialia. 2013;9(1):4457–4486.

40. Mishchenko O, Yanovska A, Kosinov O, et al. Synthetic calcium–phosphate materials for bone grafting. Polymers. 2023;15(18):3822. doi:10.3390/polym15183822
41. Jeong J, Kim JH, Shim JH, Hwang NS, Heo CY. Bioactive calcium phosphate materials and applications in bone regeneration. Biomaterials Research. 2019;23(1):4.
42. Hench LL. Bioceramics: from concept to clinic. Journal of the American Ceramic Society. 1991;74(7):1487–1510.
43. Vallet-Regí M, Ragel CV, Salinas AJ. Glasses with medical applications. European Journal of Inorganic Chemistry. 2003;2003(6):1029–1042.
44. Zhu Y, Zhang X, Chang G, et al. Bioactive glass in tissue regeneration: unveiling recent advances in regenerative strategies and applications. Advanced Materials. 2025;37(2):2312964.
45. Gavinho SR, Pádua AS, Holz LIV, et al. Bioactive glasses containing strontium or magnesium ions to enhance the biological response in bone regeneration. Nanomaterials. 2023;13(19):2717.
46. Hoppe A, Güldal NS, Boccaccini AR. A review of the biological response to ionic dissolution products from bioactive glasses and glass-ceramics. Biomaterials. 2011;32(11):2757–2774.
47. Bosetti M, Cannas M. The effect of bioactive glasses on bone marrow stromal cells differentiation. Biomaterials. 2005;26(18):3873–3879.
48. Wang M. Developing bioactive composite materials for tissue replacement. Biomaterials. 2003;24(13):2133–2151.
49. Bonfield W, Grynpas MD, Tully AE, et al. Hydroxyapatite reinforced polyethylene—a mechanically compatible implant material for bone replacement. Biomaterials. 1981;2(3):185–186.
50. Oréfice RL, Hench LL, Brennan AB. In vitro bioactivity of polymer matrices reinforced with a bioactive glass phase. Journal of the Brazilian Chemical Society. 2000;11:78–85.
51. Liverani E, Rogati G, Pagani S, et al. Mechanical interaction between additive-manufactured metal lattice structures and bone in compression: implications for stress shielding of orthopaedic implants. Journal of the Mechanical Behavior of Biomedical Materials. 2021;121:104608.
52. Frost HM. Wolff's Law and bone's structural adaptations to mechanical usage: an overview for clinicians. The Angle Orthodontist. 1994;64(3):175–188.
53. Sola A, Bellucci D, Cannillo V, Cattini A. Bioactive glass coatings: a review. Surface Engineering. 2011;27(8):560–572.
54. Algarni AA. Antibacterial agents for composite resin restorative materials: current knowledge and future prospects. Cureus. 2024;16(3).
55. Imazato S, Imai T, Russell RRB, et al. Antibacterial activity of cured dental resin incorporating the antibacterial monomer MDPB and an adhesion-promoting monomer. Journal of Biomedical Materials Research. 1998;39(4):511–515.
56. Imazato S, Russell RRB, McCabe JF. Antibacterial activity of MDPB polymer incorporated in dental resin. Journal of Dentistry. 1995;23(3):177–181.
57. Imazato S, Ebi N, Tarumi H, et al. Bactericidal activity and cytotoxicity of antibacterial monomer MDPB. Biomaterials. 1999;20(9):899–903.
58. Imazato S, Torii Y, Takatsuka T, et al. Bactericidal effect of dentin primer containing antibacterial monomer methacryloyloxydodecylpyridinium bromide (MDPB) against bacteria in human carious dentin. Journal of Oral Rehabilitation. 2001;28(4):314–319.
59. Parirokh M, Torabinejad M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview–part I: vital pulp therapy. International Endodontic Journal. 2018;51(2):177–205.
60. Giraud T, Jeanneau C, Rombouts C, et al. Pulp capping materials modulate the balance between inflammation and regeneration. Dental Materials. 2019;35(1):24–35.
61. Camilleri J, Montesin FE, Brady K, et al. The constitution of mineral trioxide aggregate. Dental Materials. 2005;21(4):297–303.
62. Taddei P, Tinti A, Gandolfi MG, et al. Vibrational study on the bioactivity of Portland cement-based materials for endodontic use. Journal of Molecular Structure. 2009;924:548–554.
63. Sarkar NK, Caicedo R, Ritwik P, et al. Physicochemical basis of the biologic properties of mineral trioxide aggregate. Journal of Endodontics. 2005;31(2):97–100.

64. Bozeman TB, Lemon RR, Eleazer PD. Elemental analysis of crystal precipitate from gray and white MTA. Journal of Endodontics. 2006;32(5):425–428.
65. Tay FR, Pashley DH, Rueggeberg FA, et al. Calcium phosphate phase transformation produced by the interaction of the Portland cement component of white mineral trioxide aggregate with a phosphate-containing fluid. Journal of Endodontics. 2007;33(11):1347–1351.
66. Liu X, Ding C, Chu PK. Mechanism of apatite formation on wollastonite coatings in simulated body fluids. Biomaterials. 2004;25(10):1755–1761.
67. Tziafas D, Pantelidou O, Alvanou A, et al. The dentinogenic effect of mineral trioxide aggregate (MTA) in short-term capping experiments. International Endodontic Journal. 2002;35(3):245–254.
68. Ramalho-Santos M, Willenbring H. On the origin of the term "stem cell". Cell Stem Cell. 2007;1(1):35–38.
69. Thomson JA, Itskovitz-Eldor J, Shapiro SS, et al. Embryonic stem cell lines derived from human blastocysts. Science. 1998;282(5391):1145–1147.
70. Engler AJ, Sen S, Sweeney HL, Discher DE. Matrix elasticity directs stem cell lineage specification. Cell. 2006;126(4):677–689.
71. Wang H, Li Y, Zuo Y, et al. Biocompatibility and osteogenesis of biomimetic nano-hydroxyapatite/polyamide composite scaffolds for bone tissue engineering. Biomaterials. 2007;28(22):3338–3348.
72. Liu H, Xu GW, Wang YF, et al. Composite scaffolds of nano-hydroxyapatite and silk fibroin enhance mesenchymal stem cell-based bone regeneration via the interleukin 1 alpha autocrine/paracrine signaling loop. Biomaterials. 2015;49:103–112.
73. Huang Y, Zhou G, Zheng L, et al. Micro-/nano-sized hydroxyapatite directs differentiation of rat bone marrow derived mesenchymal stem cells towards an osteoblast lineage. Nanoscale. 2012;4(7):2484–2490.
74. Arinzeh TL, Tran T, Mcalary J, Daculsi G. A comparative study of biphasic calcium phosphate ceramics for human mesenchymal stem-cell-induced bone formation. Biomaterials. 2005;26(17):3631–3638.
75. Ren M, Han Z, Li J, et al. Ascorbic acid delivered by mesoporous silica nanoparticles induces the differentiation of human embryonic stem cells into cardiomyocytes. Materials Science and Engineering: C. 2015;56:348–355.
76. Larranaga A, Alonso-Varona A, Palomares T, et al. Effect of bioactive glass particles on osteogenic differentiation of adipose-derived mesenchymal stem cells seeded on lactide and caprolactone based scaffolds. Journal of Biomedical Materials Research Part A. 2015;103(12):3815–3824.
77. Nayak TR, Jian L, Phua LC, et al. Thin films of functionalized multiwalled carbon nanotubes as suitable scaffold materials for stem cells proliferation and bone formation. ACS Nano. 2010;4(12):7717–7725.
78. Wu TJ, Tzeng YK, Chang WW, et al. Tracking the engraftment and regenerative capabilities of transplanted lung stem cells using fluorescent nanodiamonds. Nature Nanotechnology. 2013;8(9):682–689.
79. Akhavan O, Ghaderi E. Differentiation of human neural stem cells into neural networks on graphene nanogrids. Journal of Materials Chemistry B. 2013;1(45):6291–6301.