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Review Article

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Dental Materials: A Comprehensive Review of Evolution, Classification, Challenges and Future Prospects

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ABSTRACT

The synthesis of historical insights, current applications, and future outlooks makes this review a valuable resource for researchers, practitioners, and educators in the field of dental science.

The present comprehensive review explores the diverse applications of materials in dental science, emphasizing their pivotal role in restorative dentistry, prosthodontics, orthodontics, and periodontics. The historical evolution of dental materials sets the stage, highlighting the transition from traditional to advanced materials. Classification of dental materials encompasses restorative materials like dental amalgam, composites, and ceramics; impression materials such as alginate and elastomers; and biomaterials including dental implants, bone grafts, and membranes. Adhesive materials and their applications in bonding dental restorations are also discussed. The narrative extends to recent advance materials like amalgam and composites in dentistry. The review concludes with a discussion on challenges in dental materials and prospects for future developments.

Key Words: Materials, Dental, History, Evolution, Classification, Properties

INTRODUCTION

Engineering materials play a pivotal role in the production of items and products, influencing the selection of manufacturing methods necessary to achieve the desired shapes. In situations where multiple manufacturing processes are feasible, it is crucial to identify and utilize the most optimal process to produce the item. Therefore, it is imperative to have comprehensive knowledge of the materials available in the universe, along with their associated costs and key attributes, encompassing physical, chemical, mechanical, thermal, optical, and electrical characteristics.[1]

Understanding the manufacturing process is essential to obtain the desired product. Profound familiarity with engineering materials and their properties is of utmost importance for design and manufacturing engineers.[2] The components of tools, machinery, and equipment should be constructed from materials possessing properties that align with the operational conditions.[3] Furthermore, individuals involved in product design, tool design, and engineering design must maintain a solid grasp of diverse types of engineering materials, their characteristics, and their applications, all of which are essential in meeting the functional prerequisites of the design.[4] It is essential to comprehend how manufacturing processes and heat treatments can influence the properties of engineering materials.[5]

Dental materials are a diverse group of substances used in various aspects of dentistry to diagnose, prevent, treat, and restore oral health.[6] These materials are carefully selected to meet specific clinical requirements, such as durability, biocompatibility, aesthetics, and ease of use. The selection of dental materials is based on factors such as the specific clinical needs, aesthetics, biocompatibility, durability, and the preferences of both the dentist and the patient.[7] Advances in dental material science continue to provide dentists with a wide range of options to meet the diverse needs of their patients while ensuring optimal oral health and aesthetics.

Dental materials are used in various aspects of dental science, including restorative dentistry, prosthodontics, orthodontics, endodontics, and more. These materials are chosen based on their specific properties and applications.[8] The choice of material depends on factors like the specific dental procedure, the patient's needs, and the dentist's preferences for aesthetics, strength, and other properties.[9] Dental science continues to evolve, and new materials are developed to improve patient outcomes and satisfaction.

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The current comprehensive review explores the historical progression of dental materials sets the foundation, highlighting the shift from conventional to advanced materials, with focus on dental amalgam and composites. Additionally, the review discusses challenges and prospects in dentistry.

HISTORICAL DEVELOPMENT OF MATERIALS SCIENCE:

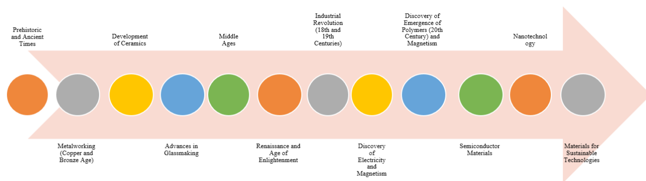

Figure 1. Historical development of materials science.

The historical development of materials science is a long and complex journey that spans millennia.[10] It has evolved from rudimentary knowledge of materials used for survival and shelter to a highly sophisticated field with significant technological and scientific implications.[11] Figure 1 represents the historical development of materials science.

Here is an overview of key developments in the historical development of materials science:

Prehistoric and Ancient Times: The earliest humans utilized natural materials like stone, wood, and animal bones for tools, weapons, and shelter.[12] This period marked the birth of materials science as humans learned to adapt and manipulate materials to meet their needs.

Metalworking (Copper and Bronze Age): The discovery and utilization of metals like copper, bronze (an alloy of copper and tin), and iron marked significant milestones. The development of metallurgy enabled the creation of more advanced tools, weaponry, and everyday objects.[13]

Development of Ceramics: Pottery and ceramics were among the first engineered materials. They played a crucial role in cooking, storage, and later, art.[14]

Advances in Glassmaking: The production of glass dates to ancient civilizations like the Egyptians and Mesopotamians.[15] It marked the emergence of materials with unique optical properties and high aesthetic value.

Middle Ages: The Middle Ages saw advancements in metallurgy, including the production of steel. Craftsmen learned to create alloys with improved strength and durability, leading to better weapons and tools.[16]

Renaissance and Age of Enlightenment: The Renaissance period led to renewed interest in scientific inquiry and experimentation, including investigations into the properties of materials. This laid the groundwork for the development of modern materials science.[17]

Industrial Revolution (18th and 19th Centuries): The Industrial Revolution brought about significant advancements in materials science, particularly in the fields of iron and steel production.[18] The Bessemer process and the development of alloys revolutionized the manufacturing industry.[19]

Discovery of Electricity and Magnetism: The19th century also witnessed the exploration of electrical and magnetic properties of materials, leading to the development of electrical insulators, conductors, and magnetic materials.[20]

Emergence of Polymers (20th Century): The 20th century saw the rise of polymers, such as synthetic plastics and rubber. The development of new polymers with various properties led to a wide range of applications, including packaging, automotive, and electronics.

Semiconductor Materials: The discovery of semiconductors like silicon and the development of semiconductor physics in the mid-20th century underpinned the modern electronics revolution.[21]

Nanotechnology: The late 20th and early 21st centuries witnessed the emergence of nanotechnology, which focuses on materials and structures at the nanoscale.[22] This has led to groundbreaking innovations in materials science, with applications in electronics, medicine, and more.[23]

Materials for Sustainable Technologies: The 21st century has seen a growing emphasis on materials for sustainable technologies, including renewable energy materials, energy storage materials, and environmentally friendly materials.[24]

Materials science has played a pivotal role in advancing various fields, including engineering, medicine, electronics, and aerospace. It continues to evolve, with researchers exploring new materials, advanced manufacturing techniques, and applications that have the potential to shape the future in fields like energy, biotechnology, and more.[25] The historical development of materials science reflects humanity's ever-expanding understanding of materials and their manipulation for the betterment of society.[26]

EVOLUTION OF MATERIALS SCIENCE IN DENTISTRY:

The evolution of materials science in dentistry has been marked by significant advances and innovations over the years, leading to improved patient care, enhanced aesthetics, and increased longevity of dental restorations.[27] Figure 2 illustrates the evolution of materials science in dentistry.

Figure 2: Evolution of materials science in dentistry.

Here is an overview of the key developments in dental materials science:

Historical Materials: In ancient civilizations, materials like gold, ivory, and bone were used for dental restorations.[28] However, these materials had limited durability and aesthetics.

Introduction of Dental Amalgam (1800s): Dental amalgam, a mixture of metals including mercury, was introduced as a restorative material in the early19th century.[29] It offered better durability than previous materials but had aesthetic and mercury safety concerns.

Invention of Dental Porcelain (Late1800s): The development of dental porcelain offered a more aesthetic option for dental restorations, although it lacked the strength and durability of contemporary materials.[30]

Advent of Composite Resins (1960s): Composite resins, tooth-colored materials, were introduced in the1960s.[31] They provided an aesthetic alternative to amalgam, improved bonding to tooth structure, and reduced the need for extensive tooth removal. This marked a significant advancement in restorative dentistry.[32]

Development of Dental Ceramics (Late20th Century): The development of stronger and more durable dental ceramics, such as lithium disilicate and zirconia, revolutionized restorative dentistry.[33] These ceramics offer excellent aesthetics, strength, and biocompatibility, making them ideal for crowns, bridges, and veneers.[34]

Advances in Adhesive Dentistry (1980s onwards): The introduction of adhesive systems, including etch-and-rinse and self-etch adhesives, significantly improved the bond between restorative materials and tooth structures.[35] This allowed for minimally invasive preparations and more conservative restorations.

Digital Dentistry and CAD/CAM (Computer-Aided Design/ Computer-Aided Manufacturing): The integration of digital technologies, including intraoral scanners and CAD/CAM systems, has transformed the field of restorative dentistry.[36] These technologies enable the design and fabrication of highly accurate and customized dental restorations, reducing the reliance on traditional impressions and manual labor.[37]

Biocompatible Implant Materials: The development of biocompatible materials, primarily titanium and zirconia, for dental implants has significantly improved the success and longevity of implant-supported restorations.[38]

Biomaterials for Guided Bone and Tissue Regeneration: The use of biomaterials like resorbable and non-resorbable membranes, bone graft materials, and bio ceramics has enhanced the success of periodontal and implant procedures, enabling guided bone and tissue regeneration.[39]

Advances in Orthodontic Materials: The evolution of orthodontic materials, such as nickel-titanium wires and ceramic brackets, has improved patient comfort, aesthetics, and the efficiency of orthodontic treatment.[40]

Development of Biocompatible Resin-Based Materials: The introduction of biocompatible resin-based materials, such as dental adhesives, impression materials, and dental polymers, has improved the overall patient experience and treatment outcomes.

Nanotechnology in Dental Materials: Researchers have explored the use of nanotechnology to enhance the properties of dental materials, such as increasing the strength and durability of composites and ceramics.[41]

The evolution of materials science in dentistry has led to improved patient care, reduced invasiveness, and enhanced aesthetics.[9] Continuous research and innovation in the field continue to advance the capabilities of dental materials, providing dentists with a wide range of options to meet the diverse needs of their patients while ensuring optimal oral health and aesthetics.[42]

TYPES OF MATERIALS IN DENTISTRY:

Figure 3 exhibit types of materials in dentistry – conventional and bio-based materials.

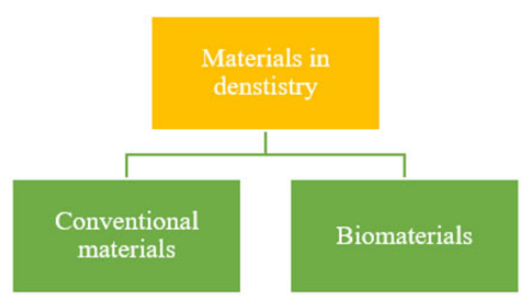

Figure 3: Types of materials in dentistry.

CONVENTIONAL MATERIALS IN DENTISTRY:

Figure 4 presents the several types of conventional materials used in dentistry.

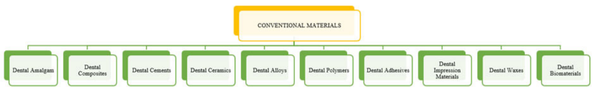

Figure 4: Types of conventional materials used in dentistry.

Here are some common classes of materials used in dental science:

Dental Amalgam: Dental amalgam is a traditional dental restorative material that contains a mixture of metals, including mercury, silver, tin, and copper.[29] It is known for its durability and is often used for filling cavities in posterior teeth.

Dental Composites: Composite resins are tooth-colored materials made from a combination of resins and fillers, such as silica or glass. They are used for direct tooth restorations, like fillings, and are aesthetically pleasing because they can match the color of natural teeth[43].

Dental Cements: Dental cements are used for various purposes, including attaching crowns, bridges, and orthodontic appliances.[44] Distinct types of cement are available, such as glass ionomer cement, resin cement, and zinc oxide-eugenol cement.

Dental Ceramics: Dental ceramics are used for making crowns, bridges, veneers, and other esthetic restorations. They are known for their natural appearance and biocompatibility. Common types include porcelain and zirconia ceramics.

Dental Alloys: Various metal alloys are used in dental science for different applications, such as cast gold alloys for crowns, and cobalt-chromium or nickel-chromium alloys for removable partial dentures.[45]

Dental Polymers: Polymers are used in various dental applications, including the fabrication of dentures, orthodontic appliances, and temporary crowns. Polymethyl methacrylate (PMMA) is commonly used for making dentures.[46]

Dental Adhesives: Adhesives are used to bond restorative materials, such as composites, to the tooth structure.[47] They play a critical role in ensuring the longevity of dental restorations.

Dental Impression Materials: These materials are used to take impressions of a patient's teeth and surrounding tissues, which are then used to create restorations, orthodontic devices, and other dental appliances. Common impression materials include alginate, polyvinyl siloxane (PVS), and polyether.[48]

Dental Waxes: Waxes are used for various purposes in dental laboratories, including the creation of patterns for casting dental restorations and the fabrication of orthodontic appliances.[49]

Dental Biomaterials: Biomaterials, such as bioceramics and biocompatible polymers, are used for applications like root canal fillings and implant materials.[50] They are designed to interact favorably with the biological environment of the oral cavity.

BIOMATERIALS IN DENTISTRY:

Figure 5 shows the several types of biomaterials used in dentistry.

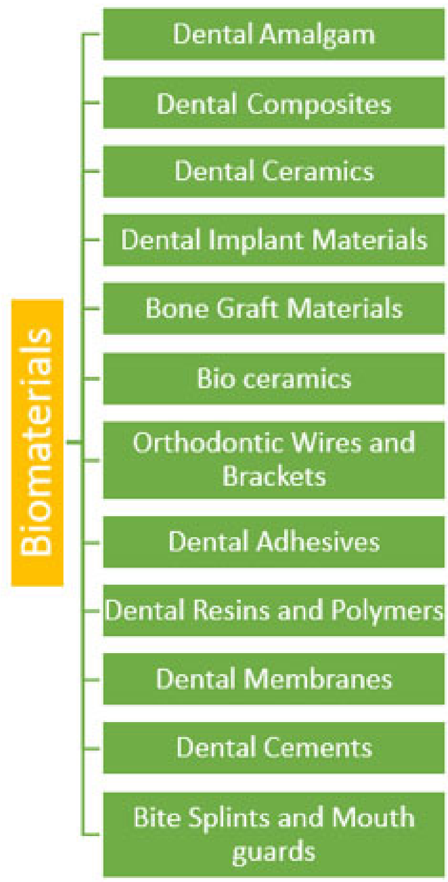

Figure 5: Biomaterials used in dentistry.

Biomaterials play a crucial role in dental science, as they are used to replace or repair damaged or missing dental tissues and structures.[50] Dental biomaterials are designed to be biocompatible, durable, and aesthetically pleasing. They are used in various aspects of dentistry, including restorative dentistry, prosthodontics, oral surgery, orthodontics, and endodontics.[51] Here are some common examples of biomaterials used in dental science:

Bone Graft Materials: Various bone graft materials, such as synthetic hydroxyapatite and demineralized bone matrix, are used in oral surgery to promote bone regeneration and support dental implant placement.[52,53].

Orthodontic Wires and Brackets: Orthodontic appliances are often made from biocompatible materials such as stainless steel, nickel-titanium, and ceramic materials. These materials are used for moving and aligning teeth.[54,55]

Dental Resins: Various dental resins and polymers are used for applications such as denture base materials, orthodontic appliances, temporary crowns and bridges.[56,57]

Dental Membranes: Membranes made from biocompatible materials like collagen or synthetic polymers are used in oral surgery and periodontics to promote tissue regeneration and barrier protection during healing.[58]

Bite Splints and Mouth guards: Biocompatible materials like silicone and ethylene-vinyl acetate (EVA) are used to fabricate bite splints, night guards, and sports mouth guards to protect teeth from damage caused by grinding, clenching, or sports-related injuries.[59]

Biomaterials in dental science continue to advance, with ongoing research and development aimed at improving their properties, biocompatibility, and longevity.[60] These materials have enhanced the practice of dentistry by offering patients a wide range of options for restoring and maintaining their oral health.

DENTAL AMALGAM:

Dental amalgam is a dental restorative material that has been used for over 150 years to fill cavities caused by tooth decay.[29] It is a mixture of several metals, with its primary components being mercury, silver, tin, and copper. Here are some key points about dental amalgam:

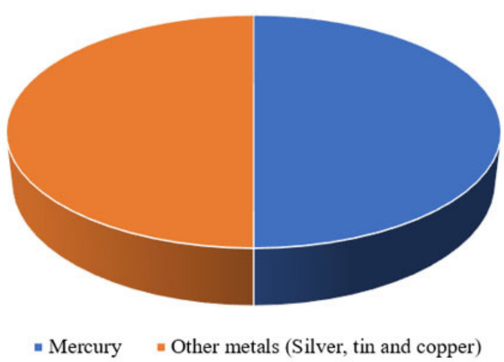

Figure 6: Composition of dental amalgam

Composition: Dental amalgam is composed of approximately 50% mercury, along with varying percentages of silver, tin, and copper.[60] The exact composition can vary among manufacturers. Figure 6 demonstrates the composition of dental amalgam.

Mercury: Mercury is a liquid metal at room temperature and plays a crucial role in dental amalgam[61]. It acts as a binder, allowing the other metal particles to mix and form a stable, durable material. However, the use of mercury in dental amalgam has raised concerns about its potential health risks[62].

Dental amalgam is renowned for its strength and durability, making it suitable for posterior teeth subjected to high biting forces. However, its silver-grey colour is a drawback, leading to a shift towards more aesthetically pleasing tooth-coloured alternatives like composite resins. While dental amalgam has a history of biocompatibility, concerns about mercury exposure and allergic reactions persist. Controversy surrounds its use due to debates on mercury toxicity, resulting in restrictions or bans in some regions. Alternatives such as glass ionomer cements and ceramics are gaining popularity. Regulatory approaches vary globally, prompting dental associations to issue guidelines. Patients are advised to consult with their dentists to weigh the advantages and disadvantages of materials, considering evolving research and advancements in dental restorative options.[63,64]

DENTAL COMPOSITES:

Dental composites, also known as composite resins or simply composites, are a popular class of dental restorative materials used in modern dentistry. They are widely used for various dental procedures, such as filling cavities, repairing tooth defects, and improving the aesthetics of teeth Here are some key points about dental composites:

Composition: Dental composites are composed of a mixture of organic resin matrix and inorganic fillers.[65] The resin matrix is typically made of a polymer, such as bisphenol A glycidyl methacrylate (Bis-GMA) or urethane dimethacrylate (UDMA). The inorganic fillers consist of finely ground glass or ceramic particles. These fillers improve the mechanical properties and wear resistance of the material.

Dental composites offer significant advantages in restorative dentistry, primarily attributed to their tooth-coloured appearance, providing an aesthetically pleasing option for visible restorations. Their versatility allows for a range of applications, from filling cavities to cosmetic enhancements like veneers. Adhering well to tooth structures, composites necessitate less tooth preparation than some alternatives. The curing process, often light-cured, ensures precise control and immediate post-procedural use. With the ability to mimic natural teeth's translucency and colour, composites are particularly favoured for cosmetic dental work. While they provide good strength and durability for smaller restorations, considerations arise for large restorations in high-stress areas, where dental amalgam or ceramics may be preferred. Notably, composites are repairable, allowing restoration of damaged or discoloured surfaces. Regular dental check-ups and oral hygiene are crucial for maintaining their appearance and longevity. Generally considered safe, dentists take precautions for potential sensitivities. As the material of choice for many visible dental restorations, the selection of dental composites involves assessing factors such as restoration size, location, patient preferences, and clinical needs.[43]

CHALLENGES AND FUTURE DIRECTIONS:

Challenges:

- Despite advancements, ensuring universal biocompatibility across diverse patient populations remains a challenge. Addressing allergic reactions or adverse responses to certain materials is crucial.
- Enhancing the durability and longevity of dental materials, especially in high-stress areas like occlusal surfaces, is a persistent challenge. This involves overcoming issues such as wear resistance and degradation over time.
- Meeting the increasing aesthetic demands of patients while maintaining material strength poses a challenge. Striking the right balance between aesthetics and durability remains a focal point for material development.
- The cost-effectiveness of advanced materials is a significant concern, especially for widespread adoption in various dental practices. Balancing innovation with affordability is essential for ensuring accessibility.
- Establishing standardized protocols and regulations for the use of advanced dental materials is challenging due to the evolving nature of the field. Consistent guidelines are crucial for ensuring safe and effective application.

Future Directions:

- Exploring the integration of nanomaterials into dental applications holds promise for enhancing material properties, including strength, antimicrobial features, and tissue integration.
- Investigating the development of smart materials that respond to stimuli like temperature, pH, or bacterial presence could revolutionize preventive and restorative dental care.
- Advancements in bioprinting and tissue engineering could pave the way for the creation of personalized, biocompatible replacements for dental tissues, offering innovative solutions for restorative dentistry.
- Leveraging data analytics, genetic information, and precision medicine concepts can lead to the development of personalized dental materials tailored to individual patient needs, improving treatment outcomes.
- Future directions should focus on the development of sustainable dental materials, considering environmental impact, recyclability, and reduced waste in the dental industry.
- Further integration of digital technologies, including artificial intelligence and machine learning, can enhance material selection, treatment planning, and overall dental care outcomes.
- Drawing inspiration from natural structures, the development of biomimetic materials aims to replicate the properties of natural tissues, improving biocompatibility and overall performance.
- Conducting extensive clinical validation and long-term studies is essential to confirm the safety, efficacy, and longevity of advanced dental materials in diverse patient populations and clinical scenarios.
- Navigating these challenges and pursuing these future directions is vital for the continued advancement of materials in dental science, leading to improved patient outcomes and a more sustainable and innovative dental industry.

DISCUSSION

The comprehensive discussion on dental materials encompasses various aspects crucial to restorative dentistry. Dental amalgam, known for strength and durability, faces aesthetic challenges due to its noticeable silver-grey colour. Concerns over potential mercury exposure and environmental impact have spurred controversy and led to restrictions in certain regions. Tooth-coloured alternatives like dental composites, prized for their natural appearance, versatility, and adhesion properties, have gained popularity. Their applications range from filling cavities to cosmetic enhancements, offering an aesthetic advantage, particularly in visible areas. The light-curing process allows for precise control, immediate use, and enhanced durability, though considerations arise for large restorations in high-stress areas. Dental composites, repairable and generally safe, demand proper care and maintenance to prevent staining or discoloration over time. The evolving landscape of dental materials involves ongoing research, with dentists guiding patients through informed decisions based on individual needs, preferences, and the evolving advancements in the field. The discussion underscores the importance of balancing aesthetic considerations, safety concerns, and functional requirements in the selection of dental materials for optimal patient outcomes.

CONCLUSION

In conclusion, the comprehensive review sheds light on the diverse applications of materials in dental science, underscoring their pivotal role across various dental disciplines. From restorative dentistry to prosthodontics, orthodontics, and periodontics, materials play a crucial role in shaping modern dental practices. The historical evolution from traditional to advanced materials reflects a dynamic field continually pushing boundaries. The classification of dental materials into categories such as restorative, impression, biomaterials, and adhesives provide a structured understanding of their applications. However, challenges persist, including biocompatibility concerns, durability issues, and the balance between aesthetics and strength. Addressing these challenges is essential for the widespread adoption of advanced materials in dental practices. Future directions include the integration of nanomaterials, the development of smart materials, and a focus on precision dentistry. Sustainable and biomimetic materials, coupled with advancements in digital technologies, hold promise for revolutionizing dental care. As the field moves toward personalized treatments and innovative solutions, the continual validation of materials through clinical studies will be critical for ensuring their safety, efficacy, and longevity. This review serves as a valuable resource for researchers, practitioners, and educators in navigating the complexities and advancements in the field of dental materials.

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Conflict of Interest:

Authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Sivamani S – Conceptualization, Administration, Supervision, Methodology, Writing – Original Draft, Anitha V - Writing Revision, Nishat Fatima - Writing Revision, Sudha Ramani - Writing Revision

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