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Biomimetics in Dentistry

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ABSTRACT

Biological systems represent millions of years of trial-and-error learning through natural selection according to the most stringent of metrics:survival. 'Biomimetics' may be defined as the practice of 'reverse engineering' ideas and concepts from nature and implementing them in a field of technology. This reverse engineering has recently attracted significant research due to an increasing realisation that many of the problems faced by engineers are similar to those already solved by nature.

Key words: Biomimetic dentistry,traditional dentistry, Tissue engineering.

INTRODUCTION

Biomimetics can be defined as "the study of stucture and function of biological systems as models for the design and engeneering of materials". It is the reconstruction of teeth to emulate their natural biomechanical an esthetic form and function. Biomimetic Dentistry is the most current, science supported approach to treating weak, fractured, and decayed teeth in a way that keeps them strong, seals them from bacterial invasion. This approach has the potenital to make restored teeth last significantly longer. Biomimetic dentistry offers several benefits in aesthetics, function, cost, pain management and overall long-term dental health.Aesthetically, when tooth is restored biomimetically, one can add depth of color, shine and shape not possible with conventional restorations. This creates a better look and feel for restored tooth, allowing it to better match the existing teeth surrounding it.

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Benefits of biomimetic dentistry

When tooth is restored biomimetically it flexes in a similar manner as natural dentin (the part of your tooth that creates the needed shock absorption during use). Hard crowns and traditional fillings do not offer this flexibility. This leads to breaks and cracks in natural teeth beneath the crown or filling and translates in to further damage and more costly dental repairs things avoided by biomimetics.

Biomimetic restorations have proven to be more cost-effective than traditional restorations because they require less expensive repairs over the life of the restoration. More than 90 percent of biomimetically-repaired teeth will never need a root canal or traditional crown. Moreover, because more of natural tooth structure is maintained in biomimetics,tooth remains healthier for longer.

Amalgam, commonly known as a silver filling, has been used for years. These fillings have no adhesive properties and simply fill space inside of your tooth. They do not support surrounding tooth structure and if left in teeth long-term swell and eventually crack and break teeth. These fillings also contain mercury, a toxic substance. Many patients are unhappy with the unaesthetic appearance of these restorations.

White composite fillings are more aesthetic and provide some adhesion properties to strengthen teeth, but with time these fillings expand and contract differently than the tooth structure and eventually leak and develop cavities beneath them.

Biomimetic fillings are very aesthetic restorations. These fillings provide a long-lasting bond to teeth that does not breakdown with time. This helps to support remaining good tooth structure and seal out bacteria that can cause recurrent cavities. Since these restorations are sealed, the postoperative sensitivity is minimal to nonexistent. These fillings are reinforced with special materials that make them as strong as the missing tooth structure they replace. This makes for a long-lasting restoration.

The foundation is critical. antibacterial, priming, bonding, layering techniques are utilized to create a protective barrier over the exposed dentin. This shields the tooth from bacterial infection ; it also adheres to the tooth with previously unachievable bond strength with documented reliability. Polymerization stresses (shrinkage) are minimized by selecting proper materials and strictly adhering to proven protocols. This creates a precision tooth-restoration system that is designed to mimic nature, so that it flexes with the tooth in function, not so strong as to break the tooth, just as strong as the tooth.

Biomimetic restorations are easily repaired upon failure and are built so that the restoration fails not the tooth. Most require little or no anesthetic to repair. The minor cost associated with repairing a biomimetic restoration is more like that of a filling rather than that of a conventional crown, root canal, bridge or implant. Traditional crown technique renders the underlying tooth structure hypo-functional due to its stiffness and rigidity. It is important to note that hypo-functionality caused by the crown technique also leads to an increased incidence of pulpal deterioration resulting in avoidable root canal treatment., gum irritation due to traditional crowns being placed under the gum to hide the metal edges.

In the long term biomimetic procedures have proven to be more time efficient. This is because everything is performed in one visit, eliminating the need for the second visit common with traditional crowns. This is also due to the conservative nature of the technique, which eliminates , root canals and other time consuming procedures that stem from the break down of conventional dental restorations.

However, the initial repair tooth is more time intensive than a traditional crown preparation or standard filling. This is because it takes time to delicately reconstruct tooth layer by layer using the most advanced techniques and adhesive materials that result in longer lasting restorations. This creates stronger teeth that are less prone to breaking or cracking and will need less work down the road, saving time and money.

Biomimetic strategies exploit these adhesive interactions to engineer bio-inspired surfaces that promote osteoblast adhesion and differentiation, bone formation, and osseointegration. These emerging initiatives focus on directing integrin binding through presentation of bio-adhesive motifs derived from extracellular matrices. These biomolecular approaches provide promising strategies for the development of biologically active implants and grafting substrates for enhanced bone repair.(1)

Biomaterial

Bulk biomaterial selected must be biocompatible,biodegradable,and have appropriate mechanical properties for load bearing applications. Metals ceramics, polymers,composites,of these metals such as titanium stainless steel and cobalt chromium are biocompatible, strong, processable and relatively inexpensive.Metals generally have a modulus higher than bone which may induce stress shielding and do not biodegrade,which requires additional surgery and may impede native tissue ingrowth.Stress shielding occurs when a fixation device has an elastic modulus substantially higher than the native tissue.The shielding prevents the native tissue and the cells within from mechanical stimulation,a primary affecter in osteoblast phenotypic behaviour. Nanofibers exist widely in human tissue with different patterns. Electrospinning nanotechnology has recently gained a new impetus due to the introduction of the concept of biomimetic nanofibers for tissue regeneration. The advanced electrospinning technique is a promising method to fabricate a controllable continuous nanofiber scaffold similar to the natural extracellular matrix. Biomedical field has become a significant possible application field of electrospun fibers.Current electrospun fiber materials include natural polymers, synthetic polymers and inorganic substances.[2]

Biomimetic strategies have great potential for tooth tissue engineering and regeneration applications—the foundation for developing strategies for reparative and regenerative medicine.

Tissue engineering & craniofacial reconstruction

The replacement of lost or deficient tissues involves the use of prosthetic materials, drug therapies, and tissue and organ transplantation. However, all of these have limitations; for example, the inability of synthetic prostheses to replace any but the simplest structural functions of a tissue. Such problems have driven the development of tissue engineering, which can be defined as a 'combination of the principles and methods of the life sciences with those of engineering to develop materials and methods to repair damaged or diseased tissues and to create entire tissue replacements.

The basic hypothesis underlying this approach is that the local delivery of an appropriate factor, at the correct dose and for a defined period of time, will lead to the recruitment, proliferation, and differentiation of cells from adjacent sites, which will then participate in tissue repair and/or regeneration at the diseased site.

A second strategy in tissue engineering makes use of cells grown in the laboratory and placed in a matrix at the site where new tissue or organ formation is desired. These transplanted cells are usually derived from a small tissue biopsy specimen and have been expanded in the laboratory to allow a large organ or tissue mass to be engineered. Typically, the new tissue will be formed in part from these transplanted cells.

Most tissue engineering efforts use biomaterials already approved by the FDA. The most widely used synthetic materials are polymers of lactide and glycolide. A natural polymer-type I collagen-is often used because of its relatively good biocompatibility and ability to be remodeled by cells. Other polymers familiar to dentistry, including alginate, are also in use.

Tissue induction

The inductive approach uses activation of cells situated close to the damaged or deficient tissue with specific signals. New bone could be formed at a nonmineralizing site after implantation of powdered bone. This discovery led to the isolation of the active ingredients from the bone powder, the cloning of the genes encoding these proteins, and their now large scale production by a number of companies. These proteins, termed bone morphogenetic proteins or BMPS, have been used in many clinical trials, including in studies on nonhealing long bone fractures and periodontal tissue regeneration, and are presently in the early phase of FDA review.

An alternative tissue-inductive approach involves placing specific extracellular matrix molecules on a scaffold support at the tissue site. These molecules will have the ability to direct the function of cells already present at that site and, therefore, to promote the formation of a desired tissue or structure.

An unresolved issue in tissue engineering is whether multiple protein signals, perhaps presented in a specific sequence, may be necessary to develop fully functional tissues.

Cell transplantation

Cell transplantation is an extremely attractive option when the inductive for a specific tissue factors are not known, when a large tissue mass or organ is needed, or when tissue replacement must be immediate.

The greatest success in this area has been the development of a tissue-engineered skin equivalent. For example, 250,000 ft^2 of skin tissue can be manufactured from a 1 in^2 sample of starting tissue. A similar approach has also been developed for replacement of oral mucosa.

The designing of polymer scaffolds with the appropriate mechanical and degradative properties has allowed investigators to engineer new cartilaginous tissues in animal models with precisely defined sizes and shapes (e.g., nasal septum and ear), which makes this method potentially useful for craniofacial reconstruction.

Two approaches are currently being studied for the development of vasculature to support the metabolic needs of the organs and for the integration of the engineered organ with the host. The first involves transplantation of endothelial cells on the scaffold with the tissue cells typed of interest. Transplanted endothelial cells can increase the vasculature in polymer scaffolds and integrate with growing host capillaries. The second approach uses localized delivery of inductive angiogenic factors at the site of the engineered tissue. Experiments on mice show that tooth rudiments can be formed in in vitro cultures of nondental stem cells, and complete teeth and associated bone can be obtained when these rudiments are transferred to adult mice.

Biomimetic tissue engineered prosthesis

The ultimate goal in the tissue engineering of the synovial joint is to fabricate biologically derived analogues that can replace severely degenerated or traumatized synovial joint components. Cell seeding density in the synthesis of chondrogenic and osteogenic matrices from human mesenchymal stem cells has been explored.[3]

An image-based approach is used to the designing and manufacturing of biomimetic tissue engineered temporomandibular (TMJ) condylar prosthesis.Tissue-engineered TMJ prosthesis utilizes a 3-D designed and manufactured biodegradable scaffold shaped similar to a condylar head and neck, i.e. a condylar-ramus unit (CRU). The fabricated CRU scaffold can be constructed with a specific intra-architectural design such that it will enhance the formation of tissue from implanted cells placed within its interstices.[4]

The ability to engineer anatomically correct pieces of viable and functional human bone would have tremendous potential for bone reconstructions after congenital defects, cancer resections, and trauma. Clinically sized, anatomically shaped, viable human bone grafts can be engineered by using human mesenchymal stem cells (hMSCs) and a "biomimetic" scaffold-bioreactor system. This approach has potential to overcome a critical hurdle—in vitro cultivation of viable bone grafts of complex geometries—to provide patient-specific bone grafts for craniofacial and orthopedic reconstructions.[5]

Biomimetics: scope

Biomimetics is the field of scientific endeavour, which attempts to design systems and synthesise materials through biomimicry. Biomeaning life and mimesis meaning imitation are derived from Greek. Perceptions regarding the scope of biomimetics appear to vary very widely depending upon the specialized discipline of the investigator. Biomedical engineers consider biomimetics as a means of conducting tissue engineering and trace the origins of biomimetics to ancient times when Mayan, Roman and Chinese civilizations had learnt to use dental implants made of natural materials. Material scientists view biomimetics as a tool for learning to synthesise materials under ambient conditions and with least pollution to the environment. Chemists have always wondered at the ease with which ammonia is produced in biological nitrogen fixation, methanol is produced in biological oxidation of methane and oxygen is generated in photosynthesis .They hope to learn the synthesis of polymers that can perform the roles of enzymes in such processes. Biologists study biomimetics not only for an understanding of the biological processes but also to trace the evolution of various classes of organisms. Biochemists have interest in the field due to the complexities associated with the interaction of biopolymers with ions of metals leading to the mineralization in living organisms. Even geologists have an interest in biomimetics because of biomineralization: the formation of extra- or intra-cellular inorganic compounds through the mediation of the living organism. Engineers attempt to explore the relationship between structure and function in natural systems with a view to achieve analogous synthetic design and manufacture.

DISCUSSION

The goals of contemporary restorative dentistry and prosthodontics should be - the maintenance of the vitality of the teeth to be restored and -
the maximum preservation of sound tooth structure. The core idea of the biomimetic principle in restorative dentistry and prosthodontics is that the intact tooth in its ideal hues and shades, and perhaps more importantly in its intracoronal anatomy, mechanics and location in the arch, is the guide to reconstruction and determinant of success. The approach is basically conservative and biologically sound. The application of the biomimetic principle involves returning all of the prepared dental tissues to full functional by the creation of a hard tissue bond that allows functional stresses to pass through the tooth, drawing the entire crown into the final functional biologic and esthetic result..The biomimetic approach is not only tooth conserving, but it is also functionally and biologically sound.

Biomimetic remineralization offers the potential for remineralizing incompletely infiltrated hybrid layers.To promote the remineralization of the imperfectly created resin-dentin interfaces a low molecular weight polyacrylic acid was used to mimic the function of Dentin matrix protein-1 on stabilizing amorphous calcium phosphate precursors and reducing the dimension of these liquid phase precursors to a nanoscale.The other biomimetic analog,polyvinylphosphoric acid is a polyanion that mimics the negative charges of phosphoproteins such as Dentin matrix protein -1,phosphoryn or bone sialoprotein.Similar to phosphoprotein molecules polyvinylphosphonic acid is conjectured to bind to demineralized collagen fibrils,thereby guiding the deposition of polyacrylic acid stabilized amorphous calcium phosphate nanoprecursors within and along specific sites of the collagen fibrils.[6]

Stem cell biology has become an important field ,cells from Dental pulp , from exfoliated deciduous teeth,apical papilla and periodontal ligament are considered as mesenchymal cells and possess different levels of capacities to become specific tissue forming cells.Human cultured periosteum sheets in combination with autogenous platelet rich plasma and hydroxyapatite granules have been used for periodontal regeneration therapy. Bone grafts of the highest utility for reconstructive surgery would be based on "designer scaffolds" shaped into gross geometries specific to the patient and defect being treated Mesenchymal stem cells (MSCs) are better suited than differentiated cells for use in cranial and maxillofacial applications owing to their easier accessibility, capability for in vitro proliferation, and potential for forming cartilage, bone, adipose, and vascular tissues.This approach can help provide a variety of anatomically shaped bone grafts designed to meet the needs of a specific patient and a specific craniofacial or orthopaedic reconstruction.[5] There are nonuniform distributions of stress and strain in the whole tooth assembly and the dissimilar mechanical responses of individual constituents due to the complicated geometries and the mismatch of material properties of individual constituents and the time dependent viscoelasticity of the periodontal ligament.A detailed quantitative evaluation of such features of both stress and strain in the periodontium is very important when analyzing the mechanically induced tooth damage as well as bone remodeling phenomenon in dentistry,since these biomechanical phenomena correlate with the levels of local stress and strain ,and distribution patterns in the entire periodontium.[7]

Molecular biomimetics is an emerging field in which hybrid technologies are developed by using the tools of molecular biology and nanotechnology. Polypeptides can now be genetically engineered to specifically bind to selected inorganic compounds for applications in nano- and biotechnology. These genetically engineered proteins for inorganics (GEPIs) can be used in the assembly of functional nanostructures. Based on the three fundamental principles of molecular recognition, self-assembly and DNA manipulation, GEPI has been successful use in nanotechnology.

Biomimetics involves 'reverse engineering'the principles of evolutionary design of biological organisms in order to implement biological solutions to general engineering problems. The problems encountered by biological systems are similar in many respects to those encountered in engineered systems .

CONCLUSION

Our teeth are a remarkable feat of biologic engineering. In fact, human teeth are designed so well that they have not changed for the past 200,000 years. Their perfect design is a balance between biologic, mechanical, functional, and esthetic parameters Biomimetics is more than copying nature, which took millions of years of a natural selection process to develop and adapt .It is the synthesis of biomaterials that mimic the physical and mechanical properties of the lost tissues, and predictably integrating them to the remaining tissues.

Nanotechnology has provided chemical molecules to fabricate submicroscopic structures. Biomimetic dentistry remains a very active area of research. By its nature, it is interdisciplinary, and it has tremendous potential for transforming everyday dental practice. Beyond the dental practice, biomimetic dental research is cross-fertilizing medical research and transforming medical practice.

Biomimetics involves the artificial synthesis of certain vitamins and antibiotics. More recently, biomimetics have been suggested as applicable in the design of machine vision systems, machine hearing systems, signal amplifiers, navigational systems, and data converters. Other possible applications of biomimetics include nanorobot antibodies that seek and destroy disease-causing bacteria, artificial organs, artificial arms, legs, hands, and feet, and various electronic devices. One of the more intriguing ideas is the so-called biochip , a microprocessor that grows from a starter crystal in much the same way that a seed grows into a tree, or a fertilized egg grows into an embryo.

Tissue-engineering provides us with the prospects of using our own cells or related cells to renovate, replace, or regenerate dysfunctional organs or tissues. This new era of biomimetics provides the opportunity to introduce and change treatment modalities for many diseases and disorders.It brings the power of modern biological, chemical, and physical science to solve real clinical problems. This should yield numerous clinical benefits in dentistry, e.g., improved treatment for intraosseus periodontal defects; enhanced maxillary and mandibular grafting procedures, possibly even allowing lost teeth to be regrown; use of devices such as an artificial salivary gland and muscle (tongue) or mucosal grafts to replace tissues lost through surgery or trauma.

"Only tight collaborations between engineers, chemists, tissue engineers, material scientists, and biologists will make these 'next-generation' materials become a reality."

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