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Bone Grafting Materials: A Literature Review

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Abstract

Bone graft materials are used widely in various types of surgeries and periodontal regenerative procedures. Different types of graft materials are available which are classified on the basis of origin of their source. The aim of the article is to classify, review and discuss mechanism of their action in brief, so that the readers can get a basic idea about different types of graft materials.

Introduction

Bone grafting is a surgical procedure that rebuilds bone by transplanting bone tissue. A dental bone graft is often required, if a patient has lost one or more adult teeth or has developed gum diseases as both problems can cause bone loss. After tooth loss, bone resorption is irreversible, leaving the area without adequate bone volume for successful dental procedures. Bone grafting is the only solution to reverse dental bone loss and is a well-accepted procedure. Bone grafts are used as pillar and scaffold over which regeneration and healing takes place. A dental graft adds volume and density to the jaw in areas where bone loss has occurred. Bone Grafting techniques have been used by specialists for more than 100 years. Many factors are involved in the successful incorporation of a graft material, including graft type, preparation site, vascularity, mechanical strength and pore size of the materials. These parameters make the use of bone substitutes challenging in terms of reliability and Predictability.1

Bone grafts are generally evaluated based on their osteogenic, osteoinductive or osteoconductive potential. Materials to be grafted can be obtained from the same person (autograft), from a different person of the same species (allografts), or from a different species (xenografts).1

Historically, autogenous bone grafts were the first bone grafts to be reported. Allogenic freeze-dried bone was introduced in early 1970s while demineralized allogenic freeze-dried bone graft gained wider application in late 1980s introductions in xenograft and Alloplastic bone grafts occur during the same time.2

Considerations that govern the selection of graft material

- Biologic acceptability
- Predictability
- Clinical feasibility
- Minimal operative hazards
- Minimal post operative sequalae
- Patient acceptance

Bone graft Properties

There are four essential elements for bone healing:

1. Osteogenic cells, example osteoblast and progenitor cells.

2. Osteoinductive signals provided by growth factors, and

3. Osteoconductive matrix

4. Adequate blood and nutrient supply.

Bone graft materials are described on the basis of

A. Osteogenesis (Presence of bone forming cells).

B. Osteoconductive (Ability to function as scaffold) and

C. Osteoinductive (ability to stimulate bone formation).

The biologic mechanism that provide a rationale for bone grafting are osteoconduction, osteoinduction and osteogenesis.4

1. Osteogenesis

Osteogenesis is the ability of the graft to produce new bone and this process is dependent on the presence of live bone cells in the graft i.e. It occurs when vital osteoblast, originating from bone graft material, contributes to the new Growth of new bone along with bone formation. Osteogenic graft material contain viable cells with the ability to form bone (osteoprogenitor cells) or the potential to differentiate into bone forming cells including Osteogenic precursor cells. Osteogenesis is a property found only in fresh autologous bone and in bone marrow cells.

2. Osteoconduction

It is a physical property of a bone graft material to serve as a scaffold for viable bone healing and new bone growth, which is perpetuated by the native bone. It allows for the growth of neovasculature and infiltration of osteogenic precursor cells into the graft site.Osteoconductive properties are found in cancellous bone autograft and allograft demineralized bone matrix, hydroxyapatite, collagen and calcium phosphate. Osteoblast forms the margin of defect that is being grafted, Utilizing the bone graft material as a framework upon which to spread and generate new bone.3In the very least, a bone graft material should be osteoconductive.

3. Osteoinduction

Osteoinduction is the ability of graft material to induce stem cells to differentiate into mature bone cells.The process is typically associated with presence of bone growth factors within the graft material or a supplement to bone graft.It Involves stimulation of osteoprogenitor cells to differentiate into

osteoblast and then begin formation of new bone. The most widely studied type of osteoinductive cell mediator is BMP.4

A bone graft material that is osteoconductive and Osteoinductive will not only serve as a scaffold for currently existing osteoblasts, but will also trigger formation of new osteoblasts promoting faster integration of the graft.

4. Osteo Promotion: -

It involves Enhancement of osteoinduction without possession of osteoinductive properties.For example, enamel matrix derivative enhances the osteoinductive effect of the demineralized freeze dried bone allograft (DFDBA) but will not stimulate bone graft alone.4

Classification

Bone replacement grafts

Human bone

– Autogenous grafts (autografts)

- Extra oral
- Intraoral

– Allogenic grafts (allografts)

- Fresh frozen bone
- Freeze dried bone allografts
- Demineralized freeze dried bone allografts

Bone substitutes

• Xenogenic grafts (xenografts)

– Bovine derived hydroxyapatite

– Coralline calcium carbonate

• Alloplastic grafts (alloplasts)

– Polymers

– Bioceramics

- Tricalcium phosphate
- Hydroxyapatite

– Bioactive glasses

Based on their biological and physical properties, bone graft can be divided into three main categories.5

Autograft

• In 1923, Hegedus attempted to use bone grafts for reconstruction of bone defects produced by periodontal disease

• This was revived by Nabers and O'Leary in 1965.

Bone form intra oral sites

• Healing extraction wounds

• Bone from edentulous ridges

• Bone trephined from within the jaw without damaging the roots

• Newly formed bone in wounds especially created for the purpose

• Bone removed during osteoplasty or ostectomy

Autogenous bone grafts are considered the standard material because they offer complete histocompatibility and provide the best osteoinductive, osteogenic and osteoconductive properties5-6.Autograft usually contain osteogenic cells, viable upto two hours in normal saline and bone matrix proteins. They provide structural support if harvested with its cortical part and get incorporated into surrounding bone through creeping substitution.6 They also suffer from resorption, limited availability, and viability. The most common source of these grafts is iliac Crest, but they can also be obtained in limited amounts from the tibial Crest and olecranon. For example, Osseous Coagulum (mixture of bone dust and blood) and bone blend (autoclaved plastic capsule and pestle)

2. Allograft

Allograft bone is osteoconductive and osteoinductive, but lacks the osteogenic properties of the autograft. Its major advantage includes availability in various shapes and sizes and no donor site morbidity. However, it only partially retains the structural strength of the autograft, although a few studies have shown disease transmission through allograft. Recent advances in processing have likely made a historical and theoretical concern7-10. There are three types of bone allograft available:

A. Fresh or frozen bone

B. FDBA

C.DFDBA

The use of allograft for the bone repair often requires sterilization and deactivation of the proteins normally found in healthy bone. Contained in extracellular matrix of bone tissue are of full cocktail of bone growth factors, proteins and other bio active materials necessary for the osteoinduction and successful bone healing. The desired factors and proteins are removed from the mineralized tissue by using a demineralizing agents such as hydrochloric acid. The mineral content of bone is degraded and the osteoinductive Agents remain in the demineralized bone matrix (DBM).

Autogenous cancellous bone is widely regarded as an ideal construct for graft procedures. Supplying osteoinductive growth factors, osteogenic cells, and structural scaffold. However, procurement, morbidity, and constraints on obtainable quantities limit its use. Allograft is the next best alternative present, however minor Immunogenicity section and risk of disease transmission are unresolved issues. Although synthetic Grafting materials eliminate this risk. These materials do not offer osteoinductive or osteogenic elements to the host site. To offer the advantage of Autograft and allograft, A composite graft may be considered. Such a graft can combine a synthetic scaffold with biological elements to stimulate cell infiltration and new bone formation.

Allogeneic bone is available in the form of a demineralized bone matrix, morselized and cancellous chips, corticocancellous and cortical grafts and osteochondral and whole bone segments.

The advantage of allograft vs autograft is that they eliminate the need of donor site during surgery and are readily available. However, the disadvantages include rejection, infection and longer healing periods and they typically result in less bone volume than autografts.8Alloplastic materials may have their greatest usefulness as autografted extenders, being added to the available autogenous bone to provide a sufficient total volume of graft material. They may also be used as carriers for growth factors, antibiotics, or other substances.

As an alternative, allogeneic bone,xenogenic bone, and alloplastic bone substitutes have been used. Advantage of these materials are good induction potential, ready availability, inexpensive elimination of

second surgical procedure, and reduced hospitalization time, Increasing demand and interest in the market Shares stimulated tissue banks and manufacturers to claim superiority Of one product over another. Due to variable physical and chemical nature among bone replacement graft, the goal of reproduction Or reconstitution of the local periodontal structure has been met with varying success or failure. These variants are:-

3. Synthetic variants

Flexible hydrogel-hydroxyapatite (HA) composite which has a mineral to organic matrix ratio, approximating that of human bone.

Artificial bone can be created from ceramics such as calcium phosphates (e.gHA and tricalcium phosphate), bioglass, and calcium sulfate are biologically active depending on solubility in the physiological environment. These materials combine with growth factors, ions such as strontium or mixed with bone marrow aspirate to increase biological activity. The presence of elements such as strontium can result in higher bone mineral density (BMD) and enhanced osteoblast proliferation.

Xenograft

Xenografts are bone grafts from a species other than human, such as bovine and are used as a calcified matrix.

Alloplastic grafts

Alloplastic grafts may be made from hydroxyapatite, a naturally occurring mineral (main mineral component of bone), made from bioactive glass. Hydroxyapatite is a synthetic bone graft, which is the most used now due to its osteoconduction, hardness, and acceptability by bone. Some synthetic bone grafts are made of calcium carbonate, which start to decrease in usage because it is completely resorbable in short time and makes breaking of the bone easier. Finally used is the tricalcium phosphate in combination with hydroxyapatite and thus giving effect of both, osteoconduction and resorbability.11

Growth factors

Growth factors enhanced grafts are produced using recombinant DNA technology. They consist of either human growth factors or morphogens (BMPs in conjunction with a carrier medium, such as collagen).

The factors and proteins that exist in bone are responsible for regulating cellular activity. Growth factors bind to receptors on cell surfaces and stimulate the intracellular environment to act. Generally, this activity translates to a protein kinase that induces a series of events resulting in transcription of

messenger ribonucleic acid (mRNA) and ultimately into the formation of a protein to be used intracellularly or extracellularly. The combination and simultaneous activity of many factors results in controlled production and resorption of bone. These factors, residing in extracellular matrix of bone, include TGF-beta, insulin like growth factors I and II, PDGF, FGF, and BMPs.12Cell-based bone graft substitutes: Stem cells are cultured in the presence of various additives such as dexamethasone, ascorbic acid, and β-glycerophosphate to direct the undifferentiated cell towards osteoblast lineage.

The addition of TGF-beta and BMP-2, BMP-4, and BMP-7 to the culture media can also influence the stem cells towards osteogenic lineage. Mesenchymal stem cells have also been seeded onto bioactive ceramics conditioned to induce differentiation to osteoblasts.

Ceramic-based bone graft substitutes

Majority of bone grafts available involve ceramics, either alone or in combination with another material (e.g., calcium sulfate, bioactive glass, and calcium phosphate). The use of ceramics, like calcium phosphates is calcium hydroxyapatite which is osteoconductive and osteointegrative; and in some cases, osteoinductive. They require high temperatures for scaffold formation and have brittle properties.13

● Calcium sulfate is also known as plaster of Paris. It is biocompatible, bioactive, and resorbable after 30-60 days. Significant loss of its mechanical properties occurs upon its degradation; therefore, it is a questionable choice for load-bearing applications:

● OsteoSet is a tablet used for defect packing. It is degraded in approximately 60 days.

● Allomatrix is Osteoset combined with DBM, forming a putty or injectable paste. OsteoSet is a calcium sulfate tablet used for bone defect sites, whereas allomatrix is a combination of calcium sulfate and DBM that forms an injectable paste or fable putty.

Bioactive glass (bioglass) is a biologically active silicate-based glass, Non resorbable material whose medical use evolved 25 years ago.The first bio active glass was invented by Dr L Hench in 1969,used in treating periodontal intra Bony defects. This in addition to being osteoconductive bonds directly to bone tissue.it is biologically active silicon based class.14, having high modulus and brittle nature; it has been used in combination with polymethylmethacrylate to form bioactive bone cement and with metal implants as a coating to form a calcium-deficient carbonated calcium phosphate layer which facilitates the chemical bonding of implants to the surrounding bone. Different types of calcium phosphates are tricalcium phosphate, synthetic hydroxyapatite, and coralline hydroxyapatite; available in pastes, putties, solid matrices, and granules.

Such calcium phosphates products include Bio-Oss and OsteoGraft. Both products use hydroxyapatite, either as a particulate (Bio-Oss) or as blocks and particulates (OsteoGraft). Pro-Osteon is a unique

product based on sea coral, which is converted from calcium carbonate to calcium hydroxyapatite. The advantage of this material is the structure of coral, which is similar to that of trabecular bone.

Bio active glass ceramics have two properties that contribute to successful results observed with its use

a) Relatively high rate of reaction with the host cells and

b) Ability to bond with the collagen found in the connective tissue.

It has been reported that high degree of bioactivity may stimulate the repair Process and induce osteogenesis because the bioactivity index is high, reaction layers develop within minutes of implantation. As a result, osteogenic cells in the implantation site may colonize the surface of the particles and produce collagen on these surfaces. Osteoblast then lays down bone material on the top of collagen. The latter action may supplement the bone that grows osteoinduction from the alveolus.

Bioglass not only bond to bone but also the soft connective tissue. Collagen is produced by Osteo genic and non osteogenic cells Example fibroblast which becomes embedded in the interfacial layer as it grows and may provide a complete Adherent interface with the graft material. The cells also appeared to lay down collagen.

Polymer-based bone graft substitutes

This can be divided into natural polymers and synthetic polymers. Subclassified into degradable and nondegradable types. Polymer-based bone graft substitutes include the following:

● Healos is a natural polymer-based product, a polymer-ceramic composite consisting of collagen fibers coated with hydroxyapatite and indicated for spinal fusions.

● Cortoss is an injectable resin-based product with applications for load-bearing sites.

Degradable synthetic polymers, like natural polymers, are resorbed by the body. The benefit of having the implant resorbed by the body is that the body is able to heal itself completely without remaining foreign bodies.

Ultimately after use of any grafts, while using any graft the expectation is that a defect will heal and some form of new bone formation will occur..

Application in dentistry

1. The most common use of bone grafting is in the application of dental implants, In order to restore edentulous area of a missing tooth. In general, bone grafts are either used in blocks such as from chin or Ascending Ramus area of the lower jaw or participated in order to be ableTo adapt better to the defect.

2. Used to fuse Joints to prevent movement, repair broken bones that have bone loss and repair broken bones that have not yet healed.

3. In case of osteonecrosis.

4. In maxillofacial surgery, in case of fracture of bone.

Conclusion

The site of reconstruction, Size of the defect to repair, objectives of the surgery, examination of the patient, desires of the patient, And the knowledge of graft materials; are all the factors that must be entertained before the surgery begins. There are many options in graft materials from which to choose, all with all advantages and disadvantages. Knowledge of this information distinguishes a good surgeon from the Great surgeon, the techniques and materials selected significantly affect outcome of bone replacement procedures in term of bone formation, volume and quality And amount of the vital bone, the choice facing the dental surgeon at a time of extraction, ridge augmentation or sinus graft are wide ranging. When choosing a bone graft material, the surgeon should consider its ultimate effect on healing pattern in and around the alveolar bone at the end point of the procedure. As this article concludes, a better understanding of the material and results that can be predictably achieved with them Can be valuable to the appropriately trained surgeon when preparing for these procedures.

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