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Mini Review

In revision hip arthroplasty, the use of ceramics as bone substitutes

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Abstract

Around the world, the number of grafting procedures, particularly those used in primary and revision hip arthroplasty, is on the rise. The demand for musculoskeletal donor tissue is presently greater than the supply. There isn't a single bone substitute that is perfect for every situation. Bone replacements are usually osteoconductive and act as a scaffold. They are rarely osteoinductive, but when they are, a molecular link is formed between the graft and the host bone, which improves fixation and lifespan. Only a small percentage of bone graft substitutes are osteogenic. In vivo use of bone graft substitutes for complicated hip arthroplasty is becoming more common, according to a growing body of clinical evidence.

Keywords: Ceramics, Grafting; Bone; Hip arthroplasty; Revision

INTRODUCTION

The repair of missing bone stock is one of the most difficult tasks facing the orthopaedic surgeon during revision arthroplasty. For both cemented and uncemented hip replacements, aseptic loosening remains the most common cause of failure. Wear particles generated by implanted materials cause an inflammatory reaction in the host, encouraging osteoclasts to resorb bone [1,2].

Bone has a sophisticated structural hierarchy that allows it to change its structure to the mechanical loads it is subjected to [3]. Because of their varying porosities, cortical and cancellous bone has different mechanical properties. Bone mineral, hydroxyapatite (Ca10(PO4)6(OH)2), accounts for around 45% of bone minerals [4]. Bone behaves in vivo as a two-phase composite made up of a collagen matrix and hydroxyapatite [5]. For situations requiring bone stock restoration, autografting is regarded as the gold standard. The approach has significant limitations that make it unfeasible in the majority of revision hip surgeries. Bulk restrictions, high rates of graft donor site morbidity and a longer operation time are among them. As a result of these restrictions, the usage of allograft has increased [6]. The Nijmegen and Exeter groups reported on the impact of grafting of both the acetabulum and femur in revision surgery in the early 1990s [7-9]. Impaction grafting, which can be done on either the femoral or acetabular side, entails creating a confined defect. Mesh, screws, bulk grafts, and other augments are used to achieve this containment. Once containment is established, the graft of choice is placed into the defect and serial tamps are used to secure it in place. To accomplish effective impaction of the graft and to provide a secure bed for eventual implantation of the prosthesis with or without cement, these tamp are gradually increased in size. Allograft bone is not consistent and varies depending on donor characteristics (donor age, bone mineralization) and processing (sterilisation and storage techniques). Impaction grafting has yielded mixed outcomes, but non-originator centres have seen improvements over time [10]. Infection is still a problem. In the United States, around 500,000 bone grafting surgeries are conducted each year. Donation rates forecasted are insufficient to meet this requirement. Due to a 100% rise in the revision burden between 1995 and 2000, it was estimated in 1998 that demand for allograft in Scotland would surpass supply by 2000. Due to a lack of supply and worries about the effects, other bone substitutes have been developed. A number of these materials have disadvantages, particularly when used in revision surgery for impaction grafting.

High compressive forces are employed in impact grafting, and collagen matrices and polyhydroxy acids lack the ability to withstand such stresses. Both xenografts and coralline grafts elicit a host response and have the potential to spread infection. Allografts osseointegrate better than xenografts, yet xenografts have the same particle size, shape, and mechanical qualities as allografts. The results of the promising series have not been duplicated, and calcium sulphate (plaster of Paris) is resorbed too quickly. Because glass ionomer and polymethylmethacrylate are not resorbed, host bone cannot replenish them. The scientist then defined an ideal bone graft substitute as one that provides structural stability, allows for neo-ossification *via* osseoconduction, osseoinduction, and substitution, is cost-effective, has an unlimited supply, and has no risk of infection transmission or provocation of a negative host response. Bone is a fundamental paradigm for tissue engineering because it allows for the implantation of a scaffold alone with the recruitment of the appropriate cells and components from the host tissue. The usage of ceramics as bone substitutes will be the subject of this review.

CERAMICS

Ceramics are non-metallic inorganic solids. Sintering is an integral aspect of the ceramics preparation process. This is accomplished by heating the ceramic to a temperature below that of melting. The density of the ceramic increases as the porosity of the ceramic decreases throughout the sintering process. The polycrystalline character of the finished ceramic is generated during the sintering process. The ultimate mechanical characteristics are heavily influenced by the grain size distribution created during this step of production. For biphasic calcium phosphate ceramics, a temperature of 900°C is required to generate grain boundaries; grain boundaries also play a significant role in determining the final mechanical properties. The presence of glass is a common feature of glass-ionomer ceramics. Sintering the glass in various quantities of SiO2, Al2O3, CaF2, and AlPO4 with or without the inclusion of hydroxyapatite produce them. They are not resorbable, as previously indicated, due to the presence of silicate and aluminium. Because the glass ionomers are non-porous, they allow only peripheral osseointegration and no osseoconduction within the particles. When implanted, they have the advantage of not causing foreign body reactions. While it is obvious that the glass ionomer gets integrated into the bone matrix, it is unknown if this is harmful or advantageous. Bone graft replacements include synthetic hydroxyapatite (Ca10(PO4)6(OH)2, tricalcium phosphate (Ca3(PO4)2), and mixtures of the two. These are made by a powder precipitating from an aqueous solution at a certain pH range. The powder is then cold pressed into tablets, which are then sintered to yield a material with a porosity by volume ranging from 1% to 5%. The insertion of elements that cause porosity inside the structure and are then burned off during the sintering process allows for osseoconduction. Glucose and naphthalene are two examples. Preparing commercially available porous Hydroxyl Apatite (HA) from natural cancellous bone is an alternative to these approaches. The mechanical and structural properties of these compounds have been shown to differ greatly among specimens. Endobon specimen densities range from 0.35 gcm-3 to 1.44 gcm-3, with the ultimate compressive stress increasing from 1 MPa to 11 MPa and the ultimate compressive modulus increasing from 0.2 GPa to 3.1 GPa. The compressive moduli of isotropic specimens were found to be higher than those of anisotropic specimens of the same density. The osseointegration of HA and Tricalcium Phosphate (TCP) has been demonstrated. In comparison to untreated cells, covering Human Bone Marrow Stromal Cells (HBMSC) with amino-acid functionalized HA nanoparticles leads to a considerable increase in osteoblast differentiation.

In immunocompromised mice, the in vivo component of this study showed comparable osteoid development after 21 days. When HBMSCs are seeded into a poly(DL-lactic acid) (PLA) graft, the results in vitro and in vivo animal models are better than when PLA is used alone. In vitro shear testing showed improved results, and in vivo testing showed a considerable rise in new bone and blood vessel creation. The structural integrity of HA and TCP is compromised under stress. For osseoconduction, a pore size of 300 μm -500 μm has been found to be optimum. When the thickness of the bridges between the pores went below a certain size, the ceramic decomposed when exposed to low compressive stresses, according to Bouler et al. The ceramic's structure can be changed in order to improve the host tissue's biological response. The goal of these manipulations is to speed up the time it takes for the construct to reach mechanical strength and so improve patient rehabilitation. It's been hypothesised that using stoichiometric hydroxyapatite instead of commercial hydroxyapatite results in a faster biological response. When compared to stoichiometric hydroxyapatite, the time it takes for an apatite layer to form in simulated bodily fluid testing was lowered by 30%. If the scaffold was not pre-treated with serum for 24 hours, the use of Bioglass in combination with a poly(DL-lactic acid) matrix had an inverse dose-related effect on osteoblast activity; if the scaffold was pre-treated with serum for 24 hours, the use of 5 wt % Bioglass composite was associated with an increase in alkaline phosphatase activity when compared to 0 wt % and 40 wt % samples. Some bioactive glasses and glass ceramics have been found to have a faster rate of bone covering and ingrowth than hydroxyapatite. Substitution of ions like sodium, magnesium, and silicon, which are present in vivo and may boost coverage and ingrowth rates, is of interest. The properties of apatite, such as lattice parameters, crystal size, and crystallinity, are affected by ionic substitution.

CLINICAL USE OF CERAMICS

In 1988, the first series on the use of ceramics (TCP) as a bone graft substitute was published. The results of 43 trauma patients were reported, and while the follow-up was brief and limited, the first findings were encouraging. In 1990, a tiny part of a series of 45 cases reported the use of hydroxyapatite ceramic as a bone graft substitute in revision arthroplasty surgery. In an ovine model, porous biphasic ceramics were found to be an effective and safe material for impaction grafting, with clinical, radiological, and histological alterations that were equivalent to the allograft. An unselected consecutive cohort of patients undergoing acetabular reconstruction during revision hip surgery was satisfactorily treated with this material. Using HA to fill severe acetabular and femoral defects during revision hip surgery, Oonishi et al. reported outstanding outcomes. Despite the fact that the joint reaction force experienced by the hip joint during arthroplasty ranges from 250% to 360% of body weight, this is the case. When employed in vivo, Oonishi et al. found that the difficulty of implantation and retention in defects, as well as the time required for bone regeneration, were the two main drawbacks of HA. Bioglass appeared to have the benefit of ease of handling and quick resorption (2 weeks vs 12 weeks for HA) in animal tests. In the medium term, coralline HA grafts have also shown satisfactory results for acetabular reconstruction in difficult revision hip surgery.

CONCLUSION

In order to be widely used as a practical and cost-effective alternative to autograft or allograft, the ideal bone graft substitute should possess a number of characteristics. With the advancement of available bone graft alternatives, the use of auto- and allograft in revision arthroplasty surgery is becoming less common. There are an increasing number of clinical trials revealing positive outcomes in the short, medium, and now long term. Long-term outcomes from a large number of patients are eagerly sought.

The prospect of restoring substantial bone loss at revision surgery by combining these absorbable substitutes with pharmacological agents, mechanical stimuli, or morphogens such as transforming growth factor beta, bone morphogenic proteins, or cartilage-derived morphogenic proteins.

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