Review Article

Review of Metallic Biomaterials in Dental Applications

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Titanium and its alloys are mainly used in manufacturing dental implants. The fact that titanium implants are immunologically very effective, new methods are being experimented to achieve utmost success rate as a biomaterial. One fundamental indicator for clinical achievement of implant is the decision of composition decided for the implant with the objective to improve osseointegration. The main objective of this study was to explore literature on dental materials used for implants, contrast them with titanium dental implants, with the aim to improve osseointegration and mechanical quality using Ti–Ga–Si dental implant.

KEYWORDS: Biomaterial, dental implants, gallium, osseointegration, silicon, titanium, titanium alloy

INTRODUCTION

A proper choice of an implant material is key factor for long haul accomplishment of dental implants. In the venture of replacing the missing tooth, numerous biomaterials been tried as an implant. Implant materials might be arranged, in light of the kinds of materials used.[1]

MATERIALS AND METHODS

This literature review started with a Google Scholar, PubMed, and ISI Web of Knowledge databases search from the year 1985 to 2018. The following key words were used to search the articles: metals, biomaterials, titanium (Ti), zirconium (Zr), gallium (Ga), silicon (Si), alloys, oral maxillofacial surgery, and dental implant. The data information was elicited (Cochrane Consumers and Communication Review Group’s information extraction format). Indicators of dental implant achievement or dismay were collected from different articles published throughout the given years. Wherever possible, full text for the articles was obtained. If it was not possible then electronically available abstracts for the articles were collected. The data information was elicited (Cochrane Consumers and Communication Review Group’s information extraction format). The inclusion criteria include: (1) Articles related to oral maxillofacial surgery and implants, and (2) Abstracts from those articles where full text was not available. Exclusion criteria include articles

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related to orthopedic surgery. The collected data are shown as contents in this paper.

**Selection of Dental Implant Material**

Metal biomaterials are being used in various forms to substitute as damaged parts or pieces to restore lost human body functions.[3] It is also used to ensure good strength, break/crack warrant uses in orthopedics for bone joints, plates, and screws and its use as braces in orthodontics implants.

Generally, metal biomaterials have enough strength, which can sustain heavy load applications of daily clinical service. Currently, the metal biomaterials useful in biomedical field are cobalt chromium alloy (CoCrMo), 316L stainless steel, Ti-based alloy (Ti–6Al–4V), and miscellaneous others (these include dental amalgam, tantalum, and gold with other “specialty” metals).[3]

Teeth-related casting mixtures (of metals) are used for making teeth-related bridges, endodontic posts, crowns to a metal (supporting structure/chemical being changed), inlays, and onlays. The noble and non-noble (base) metal mixtures (of metals) are used to form the complex shapes. Needed things include power to withstand the pressure, firmness, biocompatibility, abrasion, and chemical resistance. Compared with polymer and ceramic biomaterials, metals are seen as better electro-conductors.[4] Hence, metals are predominantly used in various biomedical dental applications. Evidence-based science advances over time, and lower success rates are reported with few metals (e.g., cobalt-chromium, stainless steel, and gold), these materials have now become obsolete. Plecko et al.[5] suggested that cobalt-chromium and steel showed lower osseointegration when compared to other metals and metal alloys. Ti and its alloys have become the metals of choice for dental implants.[6]

**Titanium**

The evolution of Ti as dental biomaterial drastically expanded in the past few years due to their excellent biocompatible, nontoxic, lasts long, non-ferromagnetic, cost-efficient, and easily available, which makes Ti the best material choice for many critical applications.[10]

**Titanium alloys as dental implants**

Ti amalgams still need enhancements when they are used as a part of dentistry. From one perspective, poor standard and low wear opposition of unadulterated Ti confines their usage in numerous regards, particularly in mass-bearing application.

Despite the fact that Ti–6Al–7Nb and Ti–6Al–4Al composites have adequate mechanical strength for fusing, both aluminum and vanadium particles contribute to many medical issues such as Alzheimer ailment, neuropathy, and osteomalacia.[11] Hence, aluminum- and vanadium-free Ti alloys came into existence because of the reviews over the years, such as Ti–In, Ti–Nb, Ti–Zr, Ti–Ge, Ti–Ta, Ti–Cu, Ti–Hf, Ti–Sn, Ti–Ag, Ti–Au, Ti–Pd, and Ti–Cu. Some of the aforementioned amalgamating elements such as molybdenum, niobium, Zr, tantalum, and hafnium are refractory metals, and if when chosen to fuse with pure Ti, it becomes strenuous for casting and gets equal composition due to phase changes.

Ti has a high melting point (1668°C) and is prone to oxidation at high temperature. Both these properties restrict its usage in dentistry.[12,13] To ease the casting procedure, fusible metals are added to lower the melting point of Ti.

During the high melting point, Ga has lower vapor pressure, which makes the Ga tough to volatilize. According to a study by Antonova and Tretyachenko,[14] when Ti is fused with Ga, it has relatively low melting temperature, thus it favors the casting procedure.[15] However, due to aesthetic problems (gray color of Ti), need has aroused for developing implant material, which mimics tooth color for better aesthetic appearance, at the same time is compatible and able to bear the load present in oral cavity; therefore, zirconia came into being.[16]

**Zirconia in dental implants**

A study investigated the survival and achievement of zirconia dental implants in light of the accessible clinical information from case reports, forthcoming and review clinical examinations, and randomized multicenter research studies.[17]

These investigations, aside from one,[18] detailed the utilization of single piece zirconia implants. The follow-up period of 5 years revealed 74%–98% survival rate and achievement rates in the vicinity of 79.6% and 91.6% following 6 years of prosthetic rebuilding. The
study results suggest that there is not enough evidence to favor the utilization of zirconia dental implants.

**Titanium–zirconium alloy**

Ti–Zi alloy of 13%–17% Zr (TiZr1317) has good mechanical properties, such as improved elongation and strength when compared to pure Ti. Fine implants and its components, which could undergo high force can be made using TiZr1317 when the material is biocompatible.[19] Ti and Zr do not hinder nor promote the osteoblast growth, which is important for osseointegration.[20]

**Gallium**

Ga occurs as gallium (III) compounds in less amounts in zinc ores and in bauxite, and not as free element naturally.[21] Ga has a major role in electronics field and has not been explored much in medical and dental field. Few research of Ga has been undertaken over the years, which shows its importance in general health, and Ga deficiency is suspected to be related with osteoporosis, Graves’ disease, cancer, ophthalmopathy, and lupus.

The results of a study show that Ga interacts with cellular particles and hydroxyapatite of bone. It shows that Ga resists bone resorption, which plays a crucial role when Ga is used in patients with osteoporosis. This is proven as clinically effective in controlling cancer-related hypercalcemia and accelerated bone resorption, which is associated with bone metastases. In this study, Ga nitrate when administered to rats, produced measurable changes in bone mineral properties. Ga was accumulated in the active bone formation regions (diaphysis). There was an increased calcium level in the bones of treated animals. The dual role of Ga over bone mineral and bone cells explains the clinical potency of inhibiting accelerated bone resorption.[22]

The following case report studies shows the actions and uses of Ga in medicine. A hyperthyroidism case report of 1988 suggests that Ga was up taken by the thyroid along with thymus, and tear gland. They took a Ga-67 scan, which showed distinct and diffuse gland of thyroid activity followed by lachrymal activity. This results led to accurate diagnosis of Graves’ disease by uptaking Ga.[23] Another case reported in 1989 showed that thyroidal Ga-67 uptake occurred frequently with subacute thyroiditis, thyroid lymphoma, anaplastic and follicular thyroid carcinoma, and rarely Hashimoto’s thyroiditis.[24]

Similar study showed Ga accumulation in right thyroid lobe of an elderly woman who showed symptoms of enlarged goiter with chest X-ray showing multiple miliary nodular lesions (first case report of this type). Open lung biopsy revealed adenomatous nodules in the right lobe and papillary carcinoma in the left lobe. This could suggest that Ga may be entangled in the causes of goiter, or directed toward the affected area as an inflammatory response by the body.[25]

The following study describes how trace elements are important in bone mineral function and bone turnover mainly in osteoporosis and in the development of skeletal structure of humans and animals. Ga and copper both play a factor in bone resorption by suppressing bone turnover, and hence benefit persons with osteoporosis. Trace elements, being the minor components in the development of bone and teeth, also play significant role in the turnover of bone. Ga was reported to suppress bone turnover rate in the malignancy of humoral hypercalcemia similar to mechanism of cadmium and aluminum. However, copper prompts lower bone turnover by controlling the functions of osteoblastic and osteoclastic cell.[26]

There are varieties of dental implants reported to be successfully placed in maxillary and mandibular bones to replace the lost tooth functions. Yet difficulties are being faced in patients with osteoporosis where osseointegration is compromised. In such cases, Ga can be used, which prevents bone lysis, which in turn stops calcium release and protects bone mass. This quality of Ga makes it to stand alone in the antiresorptive drugs.[27]

**Silicon**

Si is an essential element, which is hard crystalline solid with metallic glaze. Si is also present in animals, humans, and plants. The amount of Si in human body is considered to be 7 g, which is greater than all trace elements combined. Literature shows evidence that Si is important to human health for the development of nail, hair, bone, and skin tissues. Some studies showed that premenopausal women with higher Si dietary intake have increased bone density and suggest that Si supplementation can increase bone volume and density in patients with osteoporosis. Si is needed for the synthesis of elastin and the formation of collagen. In 1972, two studies conducted separately in animals showed similar results. One study was conducted in chickens with Si-deficient diet induced skeletal deformities and joint abnormalities. Another study was performed in rats, which resulted in defective bone growth and deformities of bone. Both studies mark the recognition of Si with their chief biological functions in the development processes of cartilage, bone, connective tissue, and skin.[28]

According to Laane,[29] Si is present in *Equisetum arvense* (horsetail) plant, which is used for therapeutic reasons such as osteoporosis, accelerated wound
healing, skin disorders, tendinitis, Alzheimer’s disease, atherosclerosis, fractures, fragile nails, and back pain. But there is insufficient information about the anabolic and catabolic activity of Si in animals and humans.

A prospective study by Eisinger et al.[29] suggested that Si brings about increased femoral bone density in women with osteoporosis, which was statistically significant \((P < 0.5)\) when compared with controls. Rico et al.[30] studied Si supplemental effect in rats with ovariectomy, which showed prevention of bone loss and also stimulated formation of bone. This suggests the therapeutic uses in cases of osteoporosis. This suggests the therapeutic uses in cases of osteoporosis.

Very little information about the use of Si in medicine and its clinical effects on human body is given in the literature of medical science. A research conducted in Amsterdam between 2004 and 2007 as an open label study with a stabilized oligomeric silicic acid and a low dose of boric acid (OSAB) was given as a liquid food supplement. OSAB is found to be beneficial and safe food additive with positive effects on bone, cartilage, tissue, skin, hair, nails, and so on. With less data regarding the metabolism of Si in human body, it cannot be proven as essential.[29]

Moreover, Si has the unique property to bind with heavy metals to form insoluble complexes, thereby possibly reducing the harmful effects.\[31\] Taking into account the effects of Si in the production of osteoblast cells, a chain of solgel-derived Si coating was developed with the parameters controlled to get materials, which is able to release Si compounds. To try out the released effects of Si, an in vitro performance of these coatings was experimented with mesenchyme stem cell of human adipose tissue, which resulted in significantly rapid increase and mineralization with high tetaethyl orthosilicate content over the coating. When compared with the uncoated control group (uncoated commercial Sandblasted/acid – etched Ti dental implant), the trial group showed greater osteoblastic activity and relatively increased bone spicules.\[32\]

Si, an absolute necessary factor in bone formation, when combined with Ga acts synergistically and shows bone construction, while it reduces bone resorption. Owing to the high need for metallic-free dental restorations, pathway was provided for the discovery of ceramic-based dental implants, such as zirconia, and alternative biomaterials, such as Si nitride or polyether ether ketone. The latter one is interesting; it can be used in oral cavity as it has been shown to have antibacterial properties. Overall among the available preclinical data, Si nitride can be used for dental implants material with essential characteristics.\[33\]

**Osseointegration of Dental Implants**

The biodegradable materials presently used in practise are generally biocompatible. Exorbitant wear and untimely corrosion will contrarily influence their biocompatibility, for example, expansion of Al or Ni increases the chances of irritation over encompassing tissue.\[34\] To some extent, this problem might be relieved if we limit immediate contact among cells and implant, for example, on account of cobalt-chromium bars that can be joined deep down utilizing more biocompatible Ti screw. Methodologies for counteractive action of bacterial pollution on cell surface associations may lead to frustrating osseointegration.\[35,36\]

When TiO\(_2\) forms over the surface of Ti implant due to oxidation, this formation of surface O\(_2\) causes osseointegration.\[37\] The success of any implant is multifactorial, including biocompatible implant material, the status of the implant bed, and a healthy and an appropriate bone morphology (bone quality) context.

**Role of silicon in bone formation**

Si is present in almost all tissues of the body mainly in bone, skin, nail, and hair.\[38\] In vitro study showed that Si empowers type-1 collagen union and osteoblast separation.\[39\] Studies in rats that were deficient in Si have shown that Si at physiologic level enhances calcium consolidation in the bone.\[40\] In a coculture of mouse bone marrow cells and RAW 264.7 cells, amorphous silica from collagen scaffolds induced a decrease in RANKL expression, and an increased activity in osteogenesis.\[41\] In this way, Si is a basic component for bone development.\[42\] An in vitro study suggested that Si promotes adherence, proliferation, differentiation, and function of osteoblasts and their precursors.\[43\]

**Gallium and silicon to improve osseointegration**

In the past few decades, more assortments of dental implants have effectively been tried over jaw bones to reestablish teeth work. Ga can straightforwardly repress lysis of bone, avoid discharge of calcium from bone, and increase bone mass, thus Ga stands alone among other antiresorptive drugs. Si, as a crucial modulator in bone arrangement, shows its bone anabolic impact and decreases bone resorption. The synergistic action of bone-forming capacity of Si and antiresorptive property of Ga will aid in the enhancement of osseointegration in osteoporotic condition.\[44\]
By increasing the efficacy and reducing the possible side effects of elemental ion, a new Ti mesoporous layer is developed by electrochemical anodization over Ti implant surface, which will serve as good local drug delivery system. Combination of Ga and Si to improve osseointegration was hypothesized to make it as a choice of material for dental implants among patients with osteoporosis.\cite{27}

**CONCLUSION**

In this literature review, dental implant biomaterials in current trend have been discussed with maximum pros and cons with few suggestions for improvement. The review structure is shown in Figure 1, and it has identified the potential use of Ti–Ga–Si as a possible dental implant. This Ti–Ga–Si is considered to combine the advantages of the Ti–Ga alloy along with Si, which enhances the osseointegration with aesthetically pleasing outcomes for the patients and minimal likelihood of medical complications.

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**Conflicts of interest**

There are no conflicts of interest.

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