DEVELOPMENT OF IMPLANTATION SYSTEMS BASED ON CARBON COMPOSITE AND TITANIUM ALLOY

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Abstract

The aimed to develop new implantation materials based on biologically inert composites. During the recent years, increase in maxillofacial injury rate caused by man-caused catastrophes, local armed conflicts and traffic accidents has been reported.

Keywords: implant, carbon materials, titanium alloys

Introduction

Due to significant environmental degradation, increase in number of patients who need surgical treatment for tumors and tumor-like lesions is evident. Facial bone injuries, gunshot wounds, tumors and tumor-like lesions lead to occurrence of defects and deformities of both osseous and soft facial tissues [1]. Tumors and traumatic injuries contribute to the emergence of serious pathological changes in the temporomandibular joints. Solving the problem of temporomandibular joint (TMJ) repair carried out after mandibular resection for space-occupying lesions, degenerative lesions, high intra-articular fractures with head splintering, is an urgent problem of modern dentistry.

Experiment

Furthermore, it should be noted that inflammatory and necrotic processes result in temporomandibular ankylosis often accompanied by organic disorders, that always requires surgery (temporomandibular disarticulation) and implant replacement of temporomandibular damaged head.

Maxillofacial defects and deformities cause severe disturbances of mastication and speech functions, can provoke sialorrhea, lead to serious changes in bite and appearance of patients. Jaw defects can cause disturbed, mixed-type breathing, sometimes dysphagia that has adverse effect on psychological state of patients and results in their social maladjustment and family status changes. Victims of local armed conflicts, terrorism, man-caused accidents and catastrophes who suffer from maxillofacial defects and deformities need adequate antiinflammatory treatment, surgical repair of anatomic shapes and functions of damaged facial bones, subsequent adequate prosthetic replacement and social rehabilitation. Numerous studies of recent years showed it was extremely difficult to provide specialized medical care to patients with maxillofacial lesions. According to WHO report, *Global goals Dentistry 2020*, prevention and treatment of acquired gnathic and temporomandibular defects have become an important strategic goal of modern dentistry [2]. That is why development of new combined implants made of biologically compatible materials used for surgical repair of bone defects and subsequent adequate prosthetic jaw replacement will permit to restore lost functionality and social adjustment in patients.

Urgency of the problem is in choosing the best adapted material for repair of gnathic defects and elimination of maxillofacial deformities in patients with jaw bone defects.

Autoplastic, alloplastic and implanted materials are used in repair mandibular defects and prosthetic replacement of temporomandibular joint. However, besides advantages, these materials may suffer from grave shortcomings, an autograft (part of the patient's own rib or ilium) failing to provide for complete restoration of anatomic shape of the jaw. The main disadvantage of autologous grafting is that it requires additional surgery which is often more serious than the main gnathic intervention. A serious disadvantage of autoplasty is than autograft dimensions and shape are difficult to model; besides, a considerable amount of bone resorption can occur after this surgery. Allografting technique (using a donor's graft) does not solve the problem, cadaveric tissue bank being unavailable. Formation of bone allograft banks has been restricted in the recent years, due to propagation of HIV infection, hepatitis B, C. Previously used reconstruction using condylar process allografts sometimes failed to succeed, both functionally and due to tissue incompatibility with pyoinflammatory complications likely to occur.

Currently, implants of various endoprosthetic materials (metals, ceramics, composites) are of great interest. Carbon composite based structures are of particular interest for specialists. They have high plastic properties, fatigue resistance, biological inertness, absence of corrosive phenomena. They are close to bone in elastic modulus, to body tissues in electric conductivity. Carbon composites have low friction wear values, composed chemically of virtually pure carbon, namely, carbon fibre and pyrocarbon [6,7]. This material is attractive by allowing to imitate all parameters of native bone, including architectonics and elastic modulus. One of the most promising materials for surgical repair of osseous defects, and success of subsequent orthopedic treatment and rehabilitation [3,4,5] is Uglekon-M (Carbulat project), a carbon composite of high biological compatibility, close to jaw bone tissue in mechanical properties.

Further improvement and use of biologically inert materials in implantation structures for gnathic defect repair accompanied by temporomandibular destruction determined urgency of the issue. Scientists of Perm State Medical University named after Academician E. A. Wagner and Scientific Center of Powder Material Science of Perm National Research University have developed an implantation system for repair of mandibular defects and prosthetic replacement of temporomandibular joint.

The structure (Fig. 1a) comprises the mandibular part (1) fabricated of a carbon composite, e.g., Uglekon-M, and the articular part (2) fabricated of a titanium alloy, e.g., BT 5Л, consisting of a head (3) and a neck (4) which replace the neck and the articular head of condylar process of mandible, and a cylindrical connecting bar (5). The articular part (2) was milled of solid titanium.

Uniqueness of the combined implantation system being proposed is in that after osteoplasty using it, mandible shape and facial aesthetics can be restored; besides, introduction of an artificial articular head normalizes vital functions: mastication, swallowing, speech, makes postoperative complications less likely, shortens the sick leave period and time of social and professional adjustment of patients having grave pathology in temporomandibular joint.

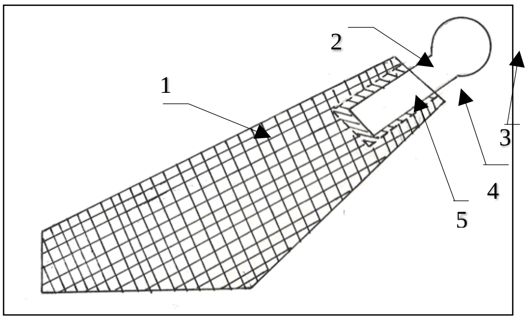

Figure 1. Implantation system used in repair of mandibular defects and prosthetic replacement of temporomandibular joint: a) structure schematic: mandibular part (1), articular part (2), head (3), neck (4), cylindrical connecting bar (5); b) finished structure

Titanium Rod-to-Uglekon-M Bonding Strength Testing

To test titanium part-to-carbon composite bonding strength, rods of 5.5-mm diameter were machined of BT3-1 titanium bar; a hole of 6-mm diameter and 10-mm depth was drilled in the carbon material and filled with titanium slip of compounds A (85% ПТ-6 + 15% TiH + 30% to 50% ethyl alcohol) and B (70% ПТ-6 + 30% TiH + 30% to 50% ethyl alcohol). The slip was prepared by mixing appropriate proportions of powdered titanium and titanium hydride in a mortar for 20 minutes. This resulted both in crushing of titanium hydride and homogenization of the powder mixture. The rod was also covered with the slip and inserted into the hole. The prepared samples were dried and heated in СНВЭ-1.3.1/16 vacuum furnace, under vacuum (residual pressure of the furnace chamber: 10^{-2} Pa), at 10 deg/min; sintering temperature was 1200°C, 1250°C, 1300°C, isothermal treatment time 1 h; the samples were cooled together with the furnace.

The bonding strength of the bar sintered into Uglekon-M was determined on samples shown in Figure 2.

Figure 2. Sample for determining titanium rod-to-carbon composite bonding strength

The titanium rod-to-Uglekon-M bonding data is given in Figure 3.

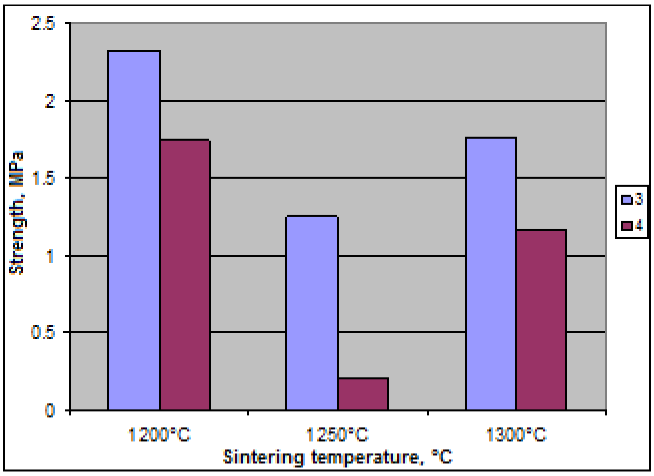

Figure 3. Titanium rod-to-carbon composite bonding strength as a function of the slip composition and the sintering temperature

The chart shows that the bonding strength is higher above 1200°C which may be attributed to lower embrittlement of the carbon material at lower temperature. As sintering temperature increases, more titanium carbide is formed at the titanium-to-carbon interface. Titanium carbide being a brittle and hard phase and the transition layer being rather porous, the coupling strength is reduced considerably. Increase in titanium hydride content of the slip reduces the bonding strength due to formation of unstable phases during heat treatment, and decrease in strength of the substrate, the carbon material.

In all samples tested, the titanium layer sintered to the rod is detached from the carbon material, particles of the latter leaving some traces on titanium. Thus, fracture has adhesive type, the transition layer consisting mostly of titanium carbide which is the most fragile component of the compound.

The sample microstructure examination showed the titanium coating to consist of 10-µm to 100-µm particles. The particles are linked by necks formed during sintering due to surface diffusion and bulk diffusion which result in mass transfer to the contact isthmus region. One can see rather close adherence of the titanium layer particles to the carbon material, absence of any delamination traces between the coating and the substrate, which results in satisfactory adhesion extent (Fig. 4).

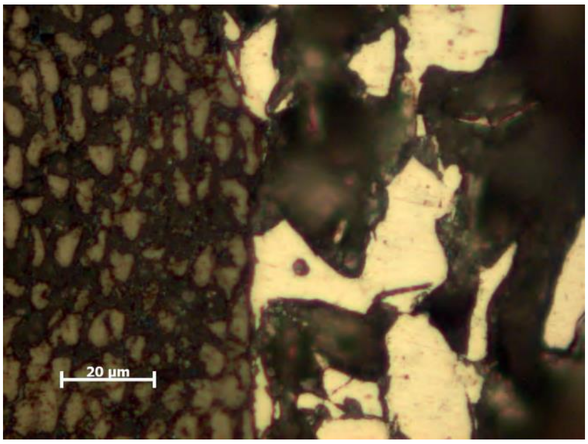

Figure 4. Microstructure of the carbon component and the titanium component after slip-aided sintering (sintering: 1200°C, ×1000)

Conclusion

1). The slip-aided titanium rod-to-carbon composite bonding strength was examined as a function of sintering temperature. The maximum titanium component-to-carbon component bonding strength is 2.32 MPa, and is observed at sintering temperature of 1200°C.

2). The microstructure of the coating and the transition layer was examined, an $\alpha+\beta$-titanium layer was shown to result from sintering of titanium slips. Titanium particles are seen to adhere rather closely to Uglekon-M.

Thus, the research data showed that further test of the implantation system developed are required, to study its medical and biological properties.

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