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Osseointegration features of orthopedic Ti–10Si–5B implants

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ABSTRACT

The present work reports on osseointegration features in rabbit tibia of orthopedic Ti–10Si–5B implants, which present a typical structure formed by the Ti and Ti_6Si_2B phases. No inflammatory reaction or rejection was noted after implantation for sixteen weeks of smooth and rough Ti–10Si–5B screw implants. Results indicated that the removal force for Ti–10Si–5B screws was continuously increased after implantation for sixteen weeks, suggesting that the bone integration process was achieved. Histological analysis revealed the occurrence of normal bone tissue growth and the presence of osteoblasts near the metal–tissue interface. Higher torque values were used to remove the rough Ti–10Si–5B screw implants after sixteen weeks, denoting that the surface treatment provided superior anchor for bone tissues. The absence of inflammatory reaction during implantation of orthopedic Ti–10Si–5B implants for sixteen weeks denotes the good bone compatibility of the composition alloy.

1. Introduction

Various medical and dental devices such as surgical instrument, endoprosthesis and orthodontic components have been developed with different metals including the stainless steels (ASTM F-138, 304 and 316 L), Co–Cr–Mo alloys and titanium and its alloys [1,2,3,4]. Depending on the implanted biomedical device an adequate balance between biological and engineering characteristics must be attempted. The bone integration and wear resistance properties are mainly required in biomedical devices used for osseointegration and articulate prostheses, respectively [2,3].

Biomaterial can be defined as an ideal bone implant material as having a compatible chemical composition to avoid adverse tissue reaction, excellent corrosion resistance in the physiologic milieu, acceptable strength, a high wear resistance and similar elastic modulus like bone for minimizing bone sorption around the implant [2]. Notoriously, the compatibility implant features influence directly on the bone integration process [5,6].

Titanium alloys are widely used for biomedical applications due to their good compatibility, corrosion resistance, and attractive strength/weight ratio [7,8,9,10,11]. It well known that the titanium presents activity for growing the soft and hard tissues [5,6]. The Ti–6Al–4V alloy consists in the major Ti alloy used for aerospace and biomedical applications. However, the aluminum and vanadium additions can contribute for occurrence of adverse reactions and systemic toxicity [12,13,14,15,16,17,18,19]. Titanium alloys containing Nb, Ta and/or Zr with low elastic modulus and better compatibility features were recently developed [4,7,8]. However, these new titanium alloys are based on Ti_{SS} (ss — solid solution) and present limited wear resistance for articulate prostheses because of their low hardness values. In contrast, the higher wear resistance values are found in Co–Cr–Mo alloys, which are formed by metal and intermetallic phases [2]. Nevertheless, the liberation of toxic Co and Cr ions occur after longer implantation times and a systemic toxicity can be achieved [16,17].

Ti–Si alloys are attractive for development of high-strength structural materials due to their good oxidation resistance for elevated temperatures [20]. Limited information was found on the effect of silicon on osseointegration features of metal implants [5]. Recent study indicated that the interactions between bone and silicon hydroxyapatite (Si–HA) at interfaces presented impact on bone apposition and ultimately the performance of medical implants [21]. Other work reported on the silicon-induced DNA damage pathway and its modulation by titanium plasma immersion ion implantation [22,23].

The TiB and TiB_2 compounds are used for electrodes, protective coatings and carbon nanotube production due to their extreme hardness values, elevated electric conductivity, high melting point and corrosion resistance [24,25]. Limited information was found on the effect of boron on osseointegration features of metal implants [26].

Recently, the existence of a new ternary phase in Ti–Si–B alloys with stoichiometry close to the Ti_6Si_2B, which it exists at 1250 °C in a narrow solubility region was noted [27]. In addition, two-phase ($Ti + Ti_6Si_2B$) and three-phase ($Ti + Ti_6Si_2B + Ti_5Si_3$ and $Ti + Ti_6Si_2B + TiB$) alloys containing metal or intermetallic matrix can be produced from the arc-melted and sintered Ti–Si–B alloys [28,29,30].

Preliminary studies involving in-vitro cell culture and blood compatibility tests of the Ti–10Si–5B alloy were recently conducted, adopting the titanium as reference. Results indicated uniform cell

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growing and 3.3–3.6 10^3 leucocites/mm^3 after 72 h, indicating no toxicity [26,31,32]. The present work reports on osseointegration features of orthopedic Ti–10Si–5B implants.

2. Materials and methods

2.1. Preparation of orthopedic Ti–10Si–5B implants

Ti–10Si–5B (at.%) ingots weighing close to 140 g were performed by arc melting under argon atmosphere from the high-purity raw materials, which were subsequently heat-treated at 1200 °C for 16 h in order to obtain the equilibrium structure formed by the $Ti_{SS}+Ti_6Si_2B$ phases. Two ingots were then machined in order to produce the twenty four hexagon-head screw shaped Ti–10Si–5B implants with 2.15 mm diameter and length of 4 mm. Fig. 1 shows the details on the screw dimension and threads. To evaluate the effect of surface roughness on osseointegration features of orthopedic Ti–10Si–5B implants, four screws were implanted as machined and the other twenty screws were blown with Al_2O_3 particles before implantation, which were referred hereafter in text as smooth and rough screw implants, respectively. All the smooth and rough Ti–10Si–5B screw implants were sterilized by Gamma irradiation after cleaning.

2.2. Structural evaluation of Ti–10Si–5B screw implants

The determination of the Ti_{SS} (ss — solid solution) and Ti_6Si_2B phases and topographic evaluation of smooth and rough Ti–10Si–5B screw implants were performed in a Olympus LEXT OLS3100 laser scanning confocal microscope, and a LEO 1450-VP scanning electron microscope using the secondary electron and back-scattered electron detectors. The Ti and Si contents of the Ti_{SS} (ss — solid solution) and Ti_6Si_2B phases were measured by energy dispersive spectrometry analysis.

2.3. Animals and groups

Twenty-four adult male New Zealand rabbits weighing between 3 and 4.0 kg were used in this work. The 16 rough screws Ti–10Si–5B implants were randomly separated in four groups for different implantation times of 4, 8, 12 and 16 weeks. The four smooth Ti–10Si–5B screw implants were implanted by 16 weeks only. In order to provide similar stress condition the same surgical procedure was adopted for the four animals of the control group (without implant).

The experiments on animals were followed in accordance with the ethical standards of the responsible committee on animal experimentation of the UNIVAP according to the COBEA standards.

2.4. Anesthesia and surgical techniques

The animals were kept without food since 12 h before the surgical procedure. Prior to surgery the acepromazine (1 mg/kg of body weight) was locally injected into the surgical sites of tibia metaphyse. After 20 min, the animals were anesthetized intramuscularly with an equal combination of Vetanarcol® (Konig Brazil) and xylazine (Xilazin®, Syntec Brazil) at a dose of 0.5–1.0 mL/200 g of body weight.

After the surgery, the surgical sites were tracked and detained for ten days and all the animals received prophylactic antibiotics (penicillin and benzatine) and anti-inflammatory ketopropheno at unique dose. The animals were allowed full weight bearing and movement after the surgery. The experimental times were 4, 8, 12 and 16 weeks after the surgical procedure. The animals were sacrificed

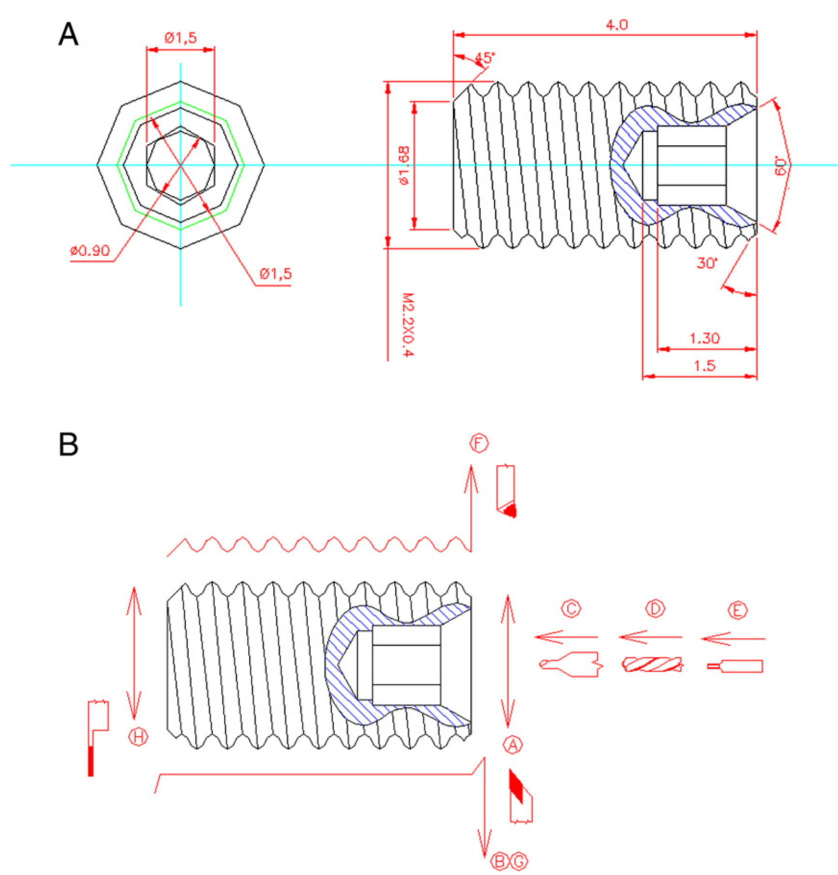

Fig. 1. Details on the dimension and thread of Ti–10Si–5B screws used in this work in (A). The sequence used during machining of screw implants is displayed in (B).