

# Bone growth around silicon nitride implants—An evaluation by scanning electron microscopy

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## ABSTRACT

Silicon nitride has demonstrated to be a potential candidate for clinical applications because it is a non-cytotoxic material and has satisfactory fracture toughness, high wear resistance and low friction coefficient. In this paper, samples of silicon nitride, which were kept into rabbits' tibias for 8 weeks, and the adjacent bone tissue were analysed by scanning electron microscopy in order to verify the bone growth around the implants and the interaction between the implant and the bone. Bone growth occurred mainly in the cortical areas, although it has been observed that the newly bone tends to grow toward the marrow cavity. Differences were observed between the implants installed into distal and proximal regions. In the first region, where the distance between the implant and the cortical bone is greater than in the proximal region, the osteoconduction process was evidenced by the presence of a bridge bone formation toward the implant surface. The results showed that silicon nitride can be used as biomaterial since the newly bone grew around the implants.

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## 1. Introduction

Silicon nitride is the preferred ceramic for high mechanical performance applications like cutting tools, components of automotive engines, gas turbines, bearings, etc. [1]. However, there are little data in the literature about the behavior of this ceramic in biological medium so that it can be used as a biomaterial [2–7]. This ceramic can be considered a great candidate for biomedical applications due to the same properties that make it so important for engineering applications: chemical stability, high wear resistance, low friction coefficient and mainly the mechanical behavior that is better than that observed for alumina ceramics [5].

The mechanical behaviour associated with its non-cytotoxicity should have an especial attention because silicon nitride based ceramics could be an alternative material to replace the alumina in many situations involving mechanical loading, as for example like artificial knee-joint, hip-balls and acetabula [3].

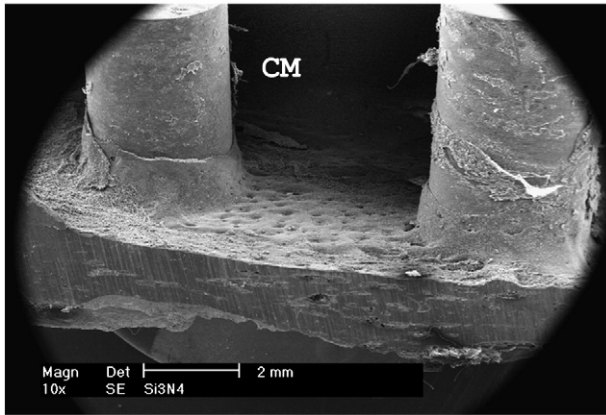
The best way to evaluate the biological performance of the material is by means of *in vivo* tests associated with light microscopy or scanning electron microscopy. Most of the available techniques to analyse the bone formation near the implants surface involve expensive experimental procedures in order to obtain micrometric thick laminae. One way to verify the bone formation around the implant is analysing the block containing the implant with surrounding bone tissue by scanning electron microscopy. Thus, in this paper the bone formation and its morphology around silicon nitride implants were evaluated by scanning electron microscopy (SEM).

## 2. Experimental Procedure

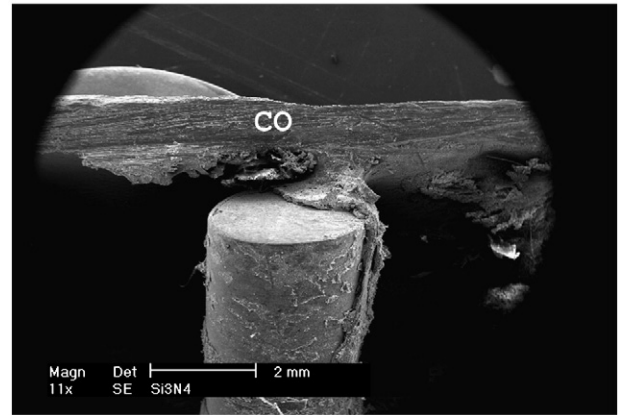
As starting materials, powders of Si<sub>3</sub>N<sub>4</sub> (M11, Hermann; with 92.7% α-Si<sub>3</sub>N<sub>4</sub> and 1.14% wt oxygen) Y<sub>2</sub>O<sub>3</sub> (Hermann C. Starck;

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**Fig. 1** – Scanning electron microscopy of the silicon nitride implants. At right, we can see the implant installed into the proximal position of the rabbit's tibia while at left, we can see the implant installed into the distal position of the rabbit's tibia. CM=Marrow cavity.



**Fig. 3** – Scanning electron microscopy of the silicon nitride implant installed into the distal position of the rabbit's tibia. It is possible to observe the bone bridge formed extending to the implant surface. CO=Compacta.

purity >99.9%); Yb<sub>2</sub>O<sub>3</sub> (Aldrich Chemical; purity >99.9%) and α-Al<sub>2</sub>O<sub>3</sub> (16 SG Alcoa, purity >99.9%) were used. In order to obtain the samples, the composition in %wt: 91Si<sub>3</sub>N<sub>4</sub>-3Y<sub>2</sub>O<sub>3</sub>-3Yb<sub>2</sub>O<sub>3</sub>-3Al<sub>2</sub>O<sub>3</sub> was ground in an attritor mill using isopropanol as liquid vehicle. The ground and homogenized powder mixture was dried at 90 °C, uniaxially pressed at 50 MPa and cold isostatic pressed at 200 MPa.

The samples were sintered at 1750 °C for 60 min in a carbon resistance furnace under nitrogen atmosphere. Analyses by X-ray powder diffraction and scanning electron microscopy showed that the sintered samples microstructure is composed by β-Si<sub>3</sub>N<sub>4</sub> grains dispersed in a glassy phase [3]. This kind of microstructure is essential to develop silicon nitride ceramics with high mechanical properties.

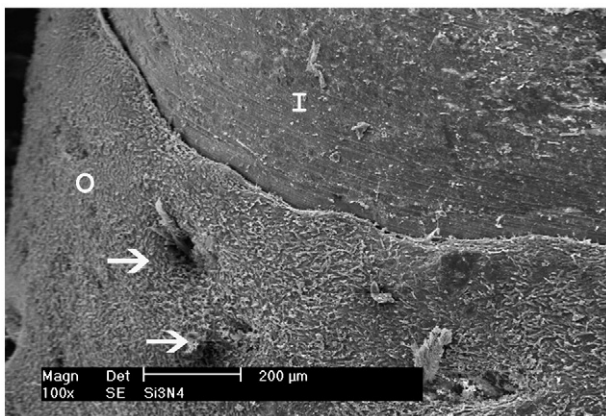
Cylindrical implants with a 3 mm diameter and a 7 mm length, manufactured from the sintered specimens, were inserted into rabbits' tibias. The implants were kept into the rabbits' tibia for 8 weeks. After this period, the implants with surrounding bone tissue were retrieved and fixed in Karnovsky solution, washed

and dehydrated, treated with osmium tetroxide and dried by the critical point method. After that, the bone was sawed so that the implants could be seen, and the block (bone and implant) was coated with gold under vacuum to be examined with a scanning electron microscope (PHILIPS—XL 30) with a voltage of 20 kV.

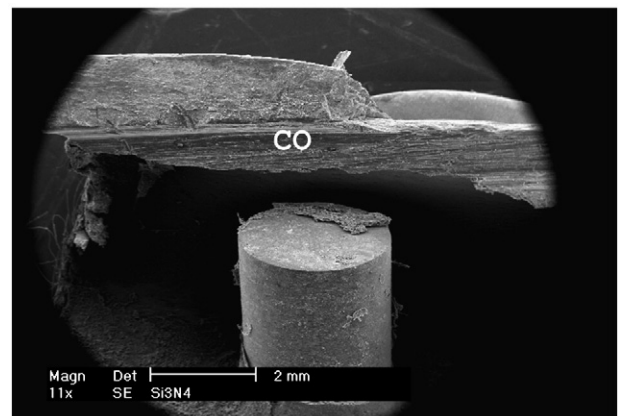
This study followed the rules of the Ethics Committee on Animals and Research (Protocol 193/02 adopted by the Brazilian College of Animal Experimentation and approved by the Biomedical Sciences Institute at the University of São Paulo).

### 3. Results and Discussion

The scanning electron microscopy demonstrated that newly bone was formed near the silicon nitride, mainly in the cortical area (see Fig. 1). The newly formed bone grew involving the implant surface and seemed to be extended toward the marrow cavity, what is an indication of osteoconduction. The morphology of the tissue adjacent to the silicon nitride implants could be



**Fig. 2** – Scanning electron microscopy of a silicon nitride implant (I). The white arrows indicate the nutrients foramina in the newly bone and the black arrow indicates the region of the interface. O=newly formed bone.



**Fig. 4** – Scanning electron microscopy of the silicon nitride implant installed into the proximal position of the rabbit's tibia. In this case the bone bridge shown on Fig. 3 was not formed. CO=Compacta.

observed. The micrographs (Figs. 1 and 2) show that the silicon nitride had a good congruency with the circumjacent bone tissue, suggesting that they promote a stable fixation when installed into the bone.

The presence of nutrient foramens in the newly bone was also noted, showing the good quality of the new bone, since these foramens are responsible to conduct the nutrient arteries to the inside of nutrient canals.

Based on the Figs. 3 and 4, we can observe that the bone growth varies according to the implant position, i.e., if the implant was installed into the distal or proximal region in the rabbit's tibia. In the distal position (see Fig. 3), where the distance between the implant surface and the superior compacta is small, the bone could grow and reach the implant, forming a bone bridge.

However, in the proximal position, bone bridges were not formed probably due to the higher distance between the implant and the original bone tissue. The gap of the distance was wider than the possibility of having an osteoconduction. Researches [8,9] are in agreement with these results by revealing that the size of the defect made during the surgical procedure for the implant installation can influence the subsequent bone-implant contact. Harris et al. [10] by their studies with total hip arthroplasty in dogs found that a gap between the bone and the implant of 0.5 mm could compromise this contact.

Also, Chang et al. [11] in their studies with zirconia, alumina and hydroxyapatite implants noted that, although the bone quality had been better in the hydroxyapatite implants, the bone quantity near the implant surface depended on its contact with the endosteum.

#### 4. Conclusions

The related results demonstrated that bone growth can occur around silicon nitride implants. Additionally, the bone formed near the silicon nitride implants had a good quality, proved by the presence of nutrients foramens.

Depending on the implant position and, consequently, on the initial distance bone-implant, bone bridges can be formed from the original compacta toward the implant surface, indicating the osteoconductivity capacity of the material.

Theses results, together with observations by in vitro test of cytotoxicity made in an earlier study [3], indicate that silicon nitride is a good candidate as biomaterial, in applications as artificial knee-joint, hip-balls, acetabulae and dental implants.

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