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Discussion

Biomechanical and Morphometric Analysis of Hydroxyapatite-Coated Implants With Varying Crystallinity

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There has been considerable discussion among those favoring the use of hydroxyapatite (HA) coatings on dental implants as to whether a coating that is quickly resorbed is more effective in achieving osteointegration than a more durable, less dissolvable coating. The resorption rate for plasma-sprayed HA coatings has been shown to be primarily a function of the percentage of crystalline HA present in the coating. The authors of this article have attempted to address the issue of coating crystallinity versus degree of osseointegration by measuring both the pullout strength and the percentage of bony contact of HA coatings of various crystallinities implanted in dogs for different periods. In addition, by including uncoated titanium implants in their study as controls, the authors have provided more in vivo evidence as to the effectiveness of HA-coated versus uncoated implants.

This study is well organized, and the methodology used provides a valid approach to determining how crystallinity influences key parameters of plasma sprayed HA coatings. The relative degree of osseointegration between implant types is usually determined by comparing values obtained by a pushout test after killing the animal. In this study, the authors have provided adequate justification for why they selected a pullout test to measure osseointegration and why the extra bonding provided by the anchored end of the implant does not measurably contribute to the bond strength. The authors used the actual bond area when calculating implant-bone bond strength (ie, osseointegration) rather than the maximum contact area possible, as is more commonly reported in the literature. To illustrate how this would affect the final results, a specimen with 70% bone contact would have lower bond strength than a specimen with 50% bone contact, even though the load to cause failure may be the same in both cases. In this case, the actual fraction of bone-to-implant contact is divided into the load required to pull out the implant to determine the integration strength in MPa or other suitable units. The authors' reported values would then be higher than those of investigators who divide load by the maximum potential contact area. However, in my opinion, the authors' methodology represents a valid approach to determining the true bone-to-implant bond strength.

The dissolution results of this study were as would be expected, with the low-crystallinity coatings showing the most degradation and the highest dissolution rate. The authors provided an assessment of the dissolution rate of the coatings by measuring the difference in the diameters of the coated implant initially and at various times in vivo. The dissolution rate of "HA" coatings is greatly influenced by their composition and porosity, including those coatings produced by plasma spraying and other methods. In a study conducted in our laboratories, we tested coatings of both high (75%) and low (46%) HA crystallinity to determine the effect of crystallinity on dissolution rate.[1] Our coatings were produced by Steri-Oss (Yorba Linda, CA) who also provided the plasma-sprayed coatings for this study. By using atomic adsorption measurements, we showed that the release of Ca was more rapid in the first few days in which the implants were immersed in a simulated physiologic solution. We found that the dissolution rate was about 3 times higher for the low-crystallinity coatings than for the high-crystallinity coatings, as indicated by the much greater release of calcium ions throughout the 6 weeks of the test. However, the rate of Ca dissolution cannot be attributed solely to the presence of a higher percentage of the amorphous phase in the low-crystallinity material. The lower-crystallinity coatings also had higher percentages of CaO, TCP, and other crystalline phases, all of which are more soluble than HA within the pH range found in the body. Calcium oxide is especially dissolvable and may account for the early release of Ca ions from both the high- and low-crystallinity coatings. Interestingly, the x-ray diffraction results after 6 weeks in solution showed that the coatings became more crystalline, with the highly crystalline coating increasing in HA content from 75% to 92%. This indicates that a significant portion of the amorphous and non-HA phases had dissolved (also supported by visual evidence), or perhaps new HA crystals had been deposited from the solution.

An important consideration when discussing osseointegration is the implant roughness, because a larger surface area contributes to interlocking with the surrounding bone and resistance when load is applied in a shear mode. The authors acknowledged that a rougher surface should increase the degree of interlocking with bone but did not take roughness measurements on their specimens. The fallacy of some past in vivo studies involving pushout tests is that the investigators compared smooth titanium surfaces with rougher plasma-sprayed surfaces and did not take into account the difference in roughness when evaluating the degree of osseointegration. However, the titanium implants used in this study were grit blasted with 50 μm alumina, so the roughness may have approached that of the grit-blasted plasma-sprayed HA-coated specimens. The reason that the measured bond strength for HA-coated implants increased with time was probably not a function of surface roughness, but rather was a result of the chemical bonding with bone, which is characteristic of these HA surfaces as opposed to uncoated titanium surfaces.

The authors measured coating thickness before and after implantation and found a great variation in thickness, as is typical with the plasma spray process. It also should be pointed out that the crystallinity of the coatings in the authors' study was adjusted to the desired amount by heat treatment, an operation that is not usually performed on commercial implants because of such factors as cost, potential for contamination, and other concerns. I am not sure why the authors stated that heat treatment might explain the difference in thickness. Any crystal growth within the amorphous regions would not change the volume of the coating material to a significant extent. If oxygen is able to diffuse to the metal surface during heat treatment, a thicker titanium oxide layer could be formed. Also, titanium phosphate or other phases could be formed at the interface because of diffusion of ions at the high temperatures experienced during heat treatment, as reported by other investigators. Heat treatment also may affect the porosity level, and that factor would influence the dissolution rate. The uneven loss of coating observed by the authors also could have resulted from damage during the insertion of the implant into bone, such as cracking or fragmentation.

Bone formation, as determined by radiolabeling, reached a maximum at 12 weeks in the authors' study. There was no trace of bony tissue remaining on the HA coatings, which is surprising because the authors had found that much of the coating had been stripped off during the pullout test and remained bonded to the bone. The scanning electron microscope also confirmed that much of the coating was dissolved at 26 weeks, as compared to very little lost at 1 week.

The 4-week data clearly suggest that HA is effective in increasing the rate of bone formation around the implant and indicate that the implant is highly osseointegrated by that time. It should be kept in mind that the implants used in this study had plasma-sprayed coatings and therefore have a number of different calcium phosphate phases present as a result of the extremely high temperatures of the process. The rapid cooling rate does not allow time for recrystallization of the coating, so a heat treatment was used to increase crystallinity of the coatings. Heat treatment is not the common commercial means of increasing the crystallinity; usually the spraying parameters (distance to substrate, gas mixture, etc.) are adjusted to change crystallinity.[2] More information is needed to determine whether the in vivo properties of an HA coating of a specific crystallinity depend to some extent on whether the crystallinity level achieved was obtained during deposition or by means of a postdeposition heat treatment. The porosity level of the coating, another factor not discussed by the authors, also may be an important factor in the dissolution behavior of the coating either in vivo or in vitro.

This study provides valuable information as to the efficacy of plasma-sprayed HA coatings, because it shows that HA, regardless of crystallinity, does provide earlier stabilization in vivo than uncoated titanium. The main contribution of the article, however, is that it shows clearly that the crystallinity of the coating does not affect the in vivo response to the implant, at least within the range of coating compositions studied. High-crystallinity coatings typically are less likely to separate prematurely from the implant by degradation of the coating-to-implant bond and may be more abrasion resistant during insertion into bone. Thus, the current efforts by most American implant companies or coating suppliers to increase the crystallinity of their commercial implant coatings appear to be validated by the results of this study.

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