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Highly crystalline MP-1™ hydroxylapatite coating Part II: *In vivo* performance on endosseous root implants in dogs

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The *in vivo* integration strength and degree of bone apposition were compared for oral endosseous implants with different plasma-sprayed hydroxylapatite (HA) coatings. Pullout strength measurements and histological analysis were used to compare two different commercially available coatings from the same manufacturer. One coating does not receive a post-plasma-spray treatment and contains about 75% crystalline HA. The other coating is treated with the MP-1™ process, a pressurized hydrothermal post-plasma-spray process, which increases the coating composition to approximately 95% crystalline HA without changing the coating's adhesive or cohesive strength. Comparisons were made in dogs after healing times of 3 and 15 weeks in the mandible. No significant differences were found in either case between the two coatings. Two different methods were used to determine the degree of bone apposition at 15 weeks. Both methods confirmed that the MP-1 process does not affect the osseointegration rate of plasma-sprayed HA coatings. Qualitative histology data suggest that the treated coating is more stable than the control coating, especially in cases of direct soft tissue attachment to the implant. The present data suggest that extensive dissolution of calcium phosphate components into surrounding tissue is not a necessary precursor for direct apposition of bone to HA-coated implants.

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For over 10 years dental implant manufacturers have applied highly crystalline hydroxylapatite (HA) to the metal surfaces of endosseous root implants using thermal-spray techniques (Block et al. 1987; Cook et al. 1987; Cook et al. 1988; Cook et al. 1992; de Groot et al. 1987; Geesink et al. 1987; Golec & Krauser 1992; Kent et al. 1990; Lugscheider et al. 1991; Stultz et al. 1993). The resultant HA coating (50–75 μm) provides an osseoconductive surface, as opposed to the bioinert surface of titanium dioxide, while the base metal substrate provides the necessary load-bearing strength required of the device.

Research on HA coatings has been abundant. The rate of osseointegration, the strength of the implant and the implant/bone interface of many different HA coatings have been extensively characterized in animals (Block et al. 1987; Cook et al. 1987; Cook et al. 1988; Cook et al. 1992; de Groot et al. 1987; Geesink et al. 1987; Cook et al. 1992; Moroni et al. 1996; Najar et al. 1991). The clinical use of HA-coated implants has also been investigated and reported on in recent years (Block & Kent 1994; Golec & Krauser 1992; Jones et al. 1997; Kent et al. 1990; Guttenberg 1993; Stultz et al. 1993).

It is well known that the chemical and morphological makeup of a plasma-sprayed HA coating does not match that of the highly crystalline feedstock (Cheang & Khor 1996; Chen et al. 1994; Klein et al. 1994a; LeGeros et al. 1995; LeGeros et al. 1993b; Lugscheider et al. 1991; Prevey & Rothwell 1994; Wang et al. 1995). The high temperatures encountered during the plasma-spray process (>15,000°C) partially decompose the HA into other calcium-containing compounds, such as amorphous calcium phosphate (ACP), α-tricalcium phosphate (α-TCP), β-tricalcium phosphate (β-TCP), tetracalcium phosphate (TTCP) and calcium oxide (CaO). ACP is essentially a non-crystalline form of HA, while the other compounds are chemically different from HA but have a crystalline morphology. Collectively these compounds can be referred to as "soluble phases" because their *in vitro* and *in vivo* solubilities are substantially higher than that of crystalline HA (LeGeros 1991; LeGeros 1993a). The soluble phase variability of commercially available plasma-sprayed HA-coated implants is reflected in the wide range of their *in vitro* solubilities (Paschalis et al. 1995). It has been speculated that one cause of the destabilization of a well-established interface between the HA coating and the surrounding bone is the *in vivo* absorption of these components (Liao et al. 1997; Gottlander et al. 1997; Cune et al. 1996).

To some degree, the relative amounts of soluble phases in an HA coating can be controlled by varying the plasma-spray parameters. However, we have observed a reduction of the adhesive and cohesive strength of the coating as the plasma-spray parameters are adjusted to create a highly crystalline HA coating. Such a reduction in strength of the coating could increase the potential for delamination of the coating *in vivo*, which is another potential cause for destabilization of the implant. Because of the proven stability and osseoconductivity of highly crystalline HA, it has been the goal of dental implant research to maximize the crystalline HA present in plasma-sprayed coatings while maintaining adequate mechanical properties. The potential benefit of such a coating could be increased long-term stability of the coating and the bone/implant interface.

A pressurized hydrothermal process (US Patent No. 5,730,598), referred to as the MP-1™ process, has been developed to improve the crystalline HA content of the Calcitite® plasma-sprayed coating (Sulzer Calcitek Inc.). Performed after plasma-spray coating deposition, the MP-1 treatment converts a typical plasma-sprayed coating comprising 75% HA, 15% ACP and 10% other soluble phases into a coating of greater than 95% crystalline HA. The remaining 5% is ACP. The final chemical composition of the treated coating is very similar to the coating feedstock material.

A substantial amount of *in vitro* testing has been conducted on the composition and the resultant solubility of the MP-1 coatings. Mechanical testing of the treated coating, including tensile, shear and fatigue analyses, has been completed. In summary, the increase in the crystalline HA content of the coating resulted in a substantial decrease in the *in vitro* solubility. The MP-1 treatment did not adversely affect the adhesion strength of the HA coating to the metal substrate or the static or fatigue strength of the base metal itself. Surface roughness was also unaffected. The results of this *in vitro* coating characterization are reported in Part I of this series (Burgess et al. 1999).

The goal of the research reported here was to determine the effects, if any, of the MP-1 process on the short-term integration rate and extent of bone apposition of the Calcitite plasma-sprayed HA coating. Additionally, the HA/host tissue interface was evaluated histologically for differences in stability of the two coatings. For clarity, the Calcitite coating will be hereafter referred to as the "control" coating and the MP-1 coating as the "treated" coating.

Materials and methods

Six adult (1-year old) beagles were screened preoperatively using radiographs to ensure that no mandibular abnormalities were present and to ascertain the appropriate implant size. HA-coated Spline® Dental Implants (Sulzer Calcitek Inc.) (4.0 mm×10 mm cylinders) from the same plasma-spray lot were placed in the mandibles of the dogs. Half of the implants were coated with the control coating, the other half with the treated coating. A total of 8 implants, 4 control and 4 treated, were placed in each dog.

Using standard general anesthesia techniques, the right and left mandibular premolars and first molar were removed. An alveoloplasty was performed to remove irregularities and to produce a flat surface for implantation. Closure was effected with absorbable sutures. Following recovery, the dogs were maintained on a soft diet for the remainder of the study. Analgesia was administered as required. Radiographs were taken to ensure complete root removal.

Eight weeks after edentulation, the implants were placed using standard techniques. All implants were spaced at least 5 mm apart and submerged 1–2 mm. The schedule of implant placement was designed to have pairs of control and treated implants positioned at equivalent loca-

tions across the mouth. For example, if the leftmost posterior position contained a control implant, the rightmost posterior position would receive a treated implant. Closure was effected using absorbable sutures. After recovery from anesthesia the animals were monitored for site healing. Soft food and water were administered *ad libitum*.

At 3 and 15 weeks following implantation, 3 dogs were euthanized. The mandibles were retrieved intact and kept moist in 0.9% saline-soaked cloths at all times. Soft tissues were removed and the mandibles were divided into 2 pieces sagitally at the midline. Each individual implant specimen was then isolated by sectioning on a water-cooled saw (Exakt, Oklahoma City, OK, USA) and labeled appropriately. All pullout tests were completed within 12 h of sacrifice. Before the mechanical testing, bone tissue at the coronal end of the implant was ground to a flat surface level with the HA coating as shown in Fig. 1. This flat surface was necessary for maintaining the correct orientation of the applied load. Mechanical testing parameters included an axial strain rate of 2 mm/min to determine the maximum failure load. After testing, all specimens were visually inspected using a stereoscopic microscope to determine the mode of interface failure. Failures were categorized as not osseointegrated, substrate/HA, HA/bone, within the HA or a combination of these. Bone attachment strength was measured by recording the force at pullout. At each timeframe, 10 of the 12 pairs (i.e., left and right specimens from the same location) were tested mechanically, while the remaining 2 pairs were prepared for intact histology.

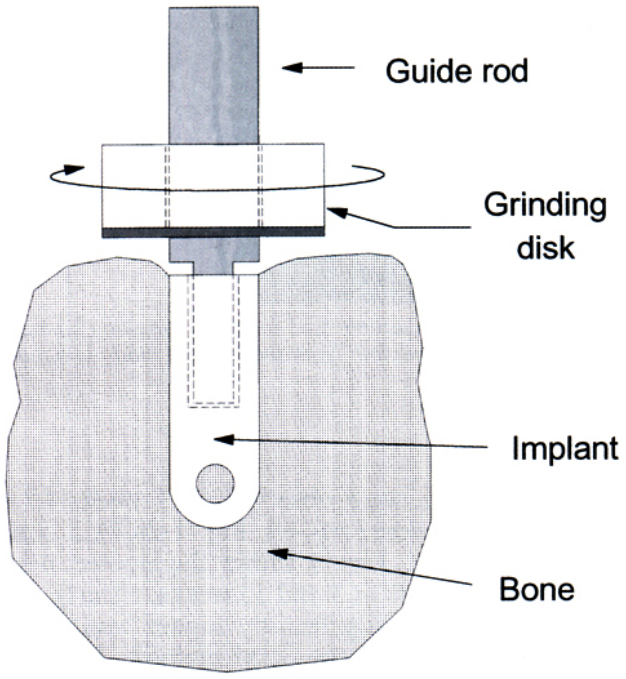

Fig. 1. Schematic illustration of the procedure used to prepare a flat bone surface for mechanical testing of the retrieved implant sample.

Basic statistical analyses included a normality test, mean, median, and standard deviation. Because the data passed the normality test, comparisons between the treated and the control groups were made using the paired Student's *t*-test.

Undecalcified histology was performed on the intact, non-tested implants. Two methods were used for determining the degree of bone apposition. The first method is based on digital analysis of backscattered electron images (SEM) (Holmes et al. 1987), while the second uses conventional light microscopy (LM). For the SEM method, retrieved specimens were placed immediately in 70% alcohol solution for fixation, followed by dehydration using a series of increasing concentrations of alcohol. They were then embedded in methacrylate-based resin (Technovit 7200vlc) and sectioned axially using a water cooled diamond blade band saw (Exakt, Oklahoma City, OK, USA). No further preparation was necessary except for gold-palladium plating. For the LM method, samples were fixed in Carnoy solution (60% ethanol, 30% chloroform, 10% acetic acid) for 2 days at 4°C and stored in 95% ethanol. After embedding in Remacryl resin, the dehydrated specimens were sectioned at 200–250 μm using a Micromet high speed rotating blade microtome, then, using an LS2 grinding machine, ground to a thickness of 40–50 μm. Samples were stained with basic fuchsin and toluidine blue. Histology was performed with KSLite image analysis software connected to the light microscope via a Hitachi KP-113 camera.

Preparation and interpretation of the histology were performed by independent laboratories, both of which were blinded as to the identity of the samples. For the 3-week samples, all histology measurements were performed using the SEM method. At 15 weeks, 1 control/treated pair was analyzed using the SEM method and the second control/treated pair was analyzed using the LM method. In addition to the extent of bone apposition, the LM technique was used to qualitatively assess the HA coatings and their *in vivo* stability.

Regardless of the method used, each implant cross section was divided into at least 6 fields of area 2 mm^2 and analyzed. Identical field locations were used for each control vs. treated pair to minimize the effects of animal variability and implant placement. Data from each implant type were also pooled and averaged for both time periods.

Results

Mechanical tests

At 3 weeks, the pullout force at failure for the treated and control implants ranged from 257 N to 751 N and 185 N to 786 N, respectively. At 15 weeks, the ranges of pullout load for treated and control implants were 480 N to 1118 N and 495 N to 1368 N, respectively. No statistically significant difference was found using a paired *t*-test analysis at 3 weeks (P=0.306) and 15 weeks (P=0.262). Data for both implant types were also pooled and averaged for both time periods. Average pullout forces as a function of time are presented in Fig. 2.

Although some bone apposition was observed for both coatings at 3 weeks, examination of the pullout failure mode of both groups suggested that the implants were not fully integrated. The HA coating remained largely intact on the implant after testing, particularly at the coronal end. At 15 weeks, pullout failure occurred within the coating (cohesive) or at the coating/implant interface (adhesive), indicating extensive integration with the surrounding bone. Both cohesive and adhesive coating failures were observed for both coatings, with examples of each failure mode presented in Fig. 3.

Histological analysis

Using the SEM method, no significant differences in bone apposition between paired control and treated implants were observed at 3 weeks (P=0.76) and 15 weeks (P=0.49). Fig. 4 shows a typical SEM sample. Fig. 5 shows the pooled data from both methods at 3 and 15 weeks. Clearly, the LM method gave significantly higher results for bone apposition than the SEM method. This difference is attributed to the ability of the LM method to reveal microscopic bone lacunae, which contribute to the overall bone apposition level but

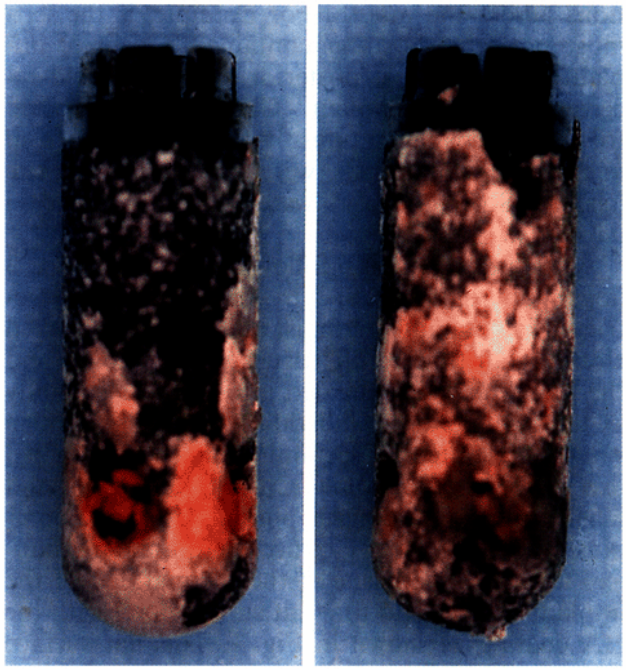

Fig. 3. Pullout failure modes of HA coated implants. Adhesive (left) and cohesive (right). Dark areas are implant body, white areas are HA.

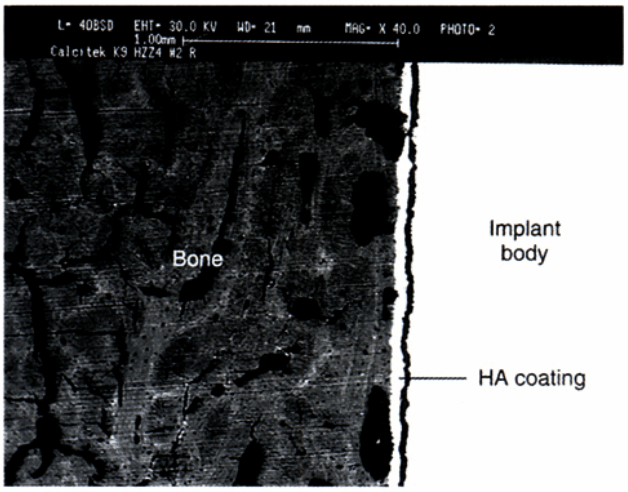

Fig. 4. Typical cross section used for SEM histology method. Separation of HA coating from the implant body is a processing artifact.

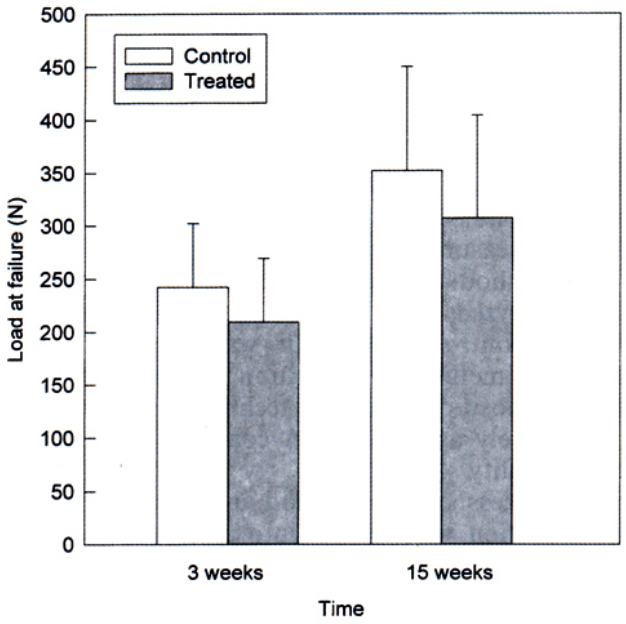

Fig. 2. Pullout forces for treated and control coated implants, showing pooled data from all samples. Mean and standard deviation shown.

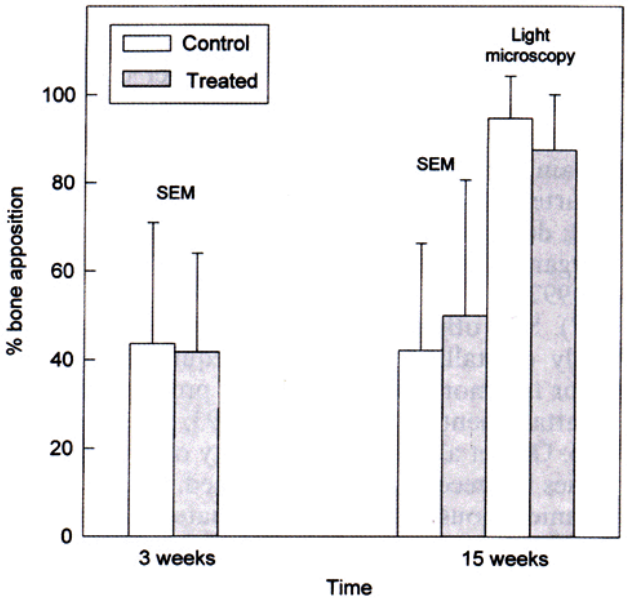

Fig. 5. Extent of bone apposition for treated and control coatings, showing pooled data from all samples. Mean and standard deviation shown.

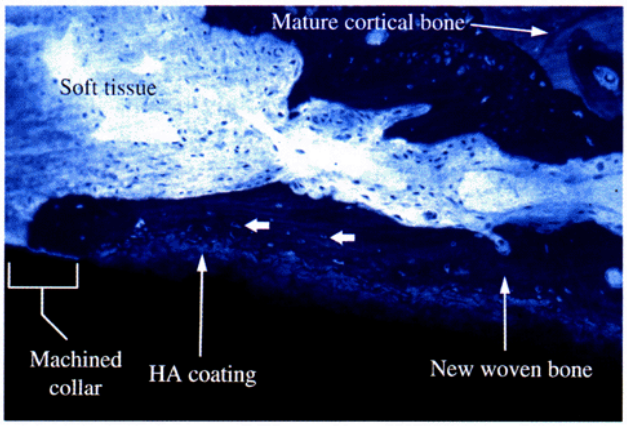

Fig. 6. Control coating at the coronal end of the implant after 15 weeks. New woven bone is forming at the coating surface. Coating particles can be seen imbedded in new bone. The space between the new bone and the Ti6Al4V machined collar appears to be a histological processing artifact.

which are apparently not detectable using the SEM method.

Tissue attachment to the coatings at 15 weeks is illustrated in Figs 6–10, as determined using the LM method. Numerous qualitative observations were made from these slides. Both coatings resulted in extensive direct apposition of new woven bone to the implant surface, seen as the darker blue stained areas of the cross sections (Figs 6–9). Fig. 7 also shows that mature cortical bone is apposed to the treated coating. Macrophages were observed near the surfaces of both samples, in some cases having phagocytized HA particles (Fig.

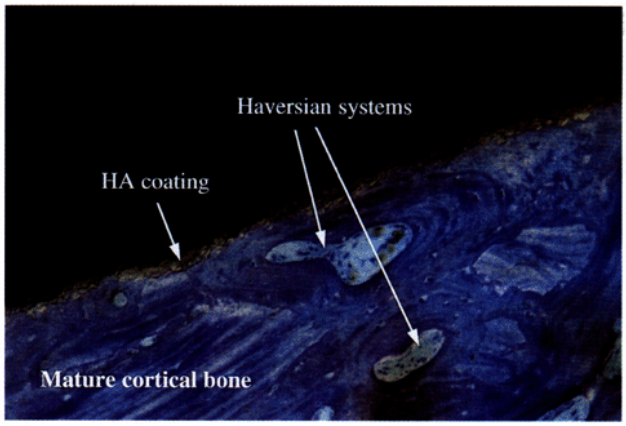

Fig. 7. Apposition of bone to the treated coating after 15 weeks. Mature cortical bone with Haversian systems is evident directly apposed to the coating surface.

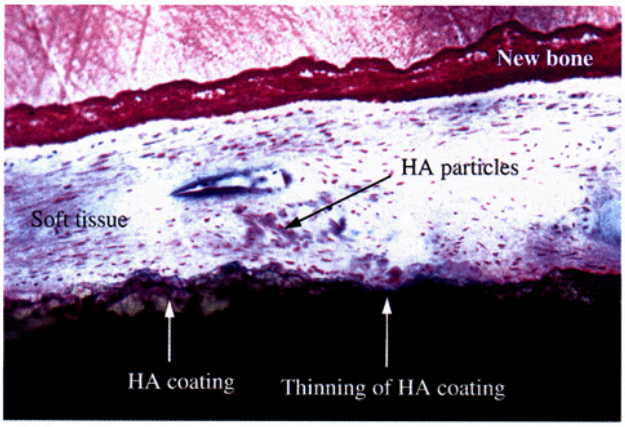

Fig. 8. Control coating/soft tissue interface at 15 weeks, showing some phagocytized HA particles.

8). These cells are commonly associated with *in vivo* absorption of implanted materials. Moreover, in areas where there was direct soft tissue attachment to the implant surface rather than bone attachment, it appeared that some thinning of the control coating had occurred. The treated coating appeared to retain its thickness and density although direct measurements were not obtained (Fig. 9).

Fig. 10 shows mature bone being remodeled adjacent to the treated coating. The cutting cone contains osteoclast-like cells at the leading edge of the cone and osteoblasts at the trailing edge. An osteoid seam is being deposited as the mature bone is remodeled. In addition, Haversian systems and vasculature are clearly evident near the coating surface.

A final observation was that for the LM histology samples, the control coating was observed to darken more upon staining than the treated coating.

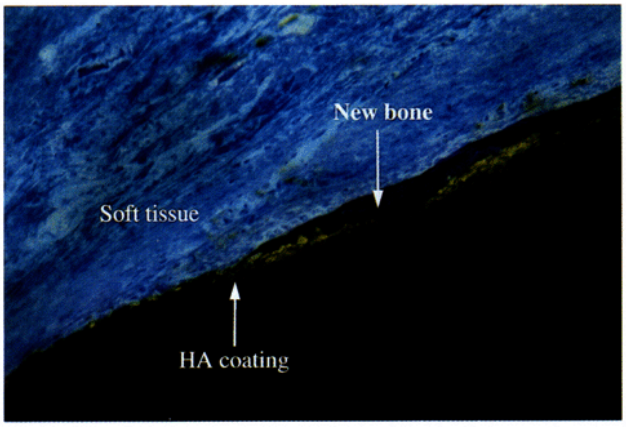

Fig. 9. Soft tissue and actively forming bone in apposition to the treated coating at 15 weeks.

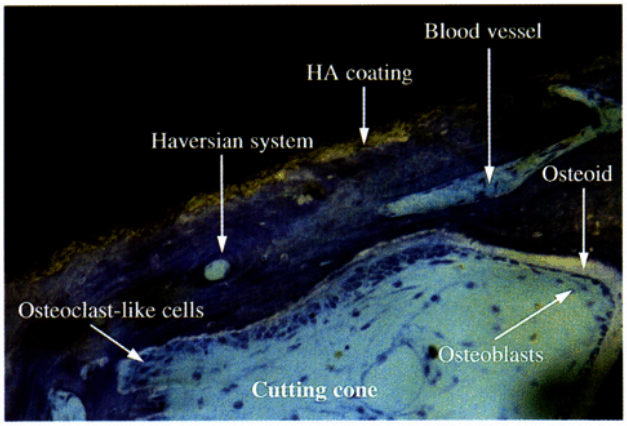

Fig. 10. Mature cortical bone and remodeling adjacent to the treated coating. Haversian systems and a classical cutting cone seen with remodeling are evident. A blood vessel is seen near the surface as indicated by the endothelial lining.

Discussion

It was the intent of this study to compare the *in vivo* performance of two different commercially available implant coatings, using the commercial implant configuration. For this reason, the implants in this study featured apical "vent holes". Because the same implant body was used for all samples, direct comparisons of the mechanical data from this study are justified. Absolute pullout force is reported here rather than pullout stress. Because attached bone at the apical hemispherical end was not removed, it was impossible to assign a consistent area for stress calculation. Additionally, as mentioned above, the implants in this experiment featured apical vent holes which could not easily be accounted for in an area calculation.

There are conflicting data in the literature about the effects of HA crystallinity on osseointegration. It has been suggested that the osseointegration mechanism for HA-coated implants involves the release of calcium from the coating into surrounding tissue (LeGeros 1993a). A number of *in vitro* studies have concluded that cell attachment is more extensive on plasma-sprayed coatings which contain a significant fraction of soluble phases (Courteney-Harris et al. 1995; de Bruijn et al. 1993; de Bruijn et al. 1994; Frayssinet et al. 1994; Morgan et al. 1996; Radin et al. 1998; Suzuki et al. 1997; van Blitterswijk et al. 1994; Weng et al. 1997). Still other *in vitro* studies have found that highly crystalline coatings are equivalent or superior to amorphous coatings in promoting cellular attachment (Cotell et al. 1993; Hoppe et al. 1996; Ong et al.1998). The validity of such *in vitro* studies has recently been questioned, as immersion of amorphous calcium phosphate coatings in aqueous solutions such as cell culture medium can lead to dissolution/precipitation of coating components, which may in turn influence *in vitro* cell attachment (Anselme et al. 1997).

In vivo studies have also given conflicting reports on the need for soluble phases. Some authors report that soluble components, such as β-TCP, help establish a strong bone/implant interface, while others have found that highly crystalline coatings provide equal or superior bone attachment (Caulier et al. 1995; Clemens et al. 1997; Denissen et al. 1990; de Bruijn et al. 1994; de Lange & Donath 1989; Frayssinet et al. 1993; Frayssinet et al. 1994; Klein et al. 1994b; Maxian et al. 1994; Nagano et al. 1996; van Blitterswijk et al. 1993). Interpretation of these studies is not straightforward, as the animal model, implant placement, configuration and surface characterization vary widely. For example, the "highly crystalline" coatings reported are as low as 60% and as high as 100% crystalline HA (Maxian et al. 1994; Hayashi et al. 1993). Some studies use fluorapatite as a proxy for highly crystalline HA (Overgaard et al. 1998), while others do not specify crystallinity at all. Hayashi et al. (1993) concluded that the difference in the surface roughness of their highly crystalline HA implants and plasma-sprayed HA coatings may have affected the bone attachment during the early stages of healing. In our study the implant size, configuration, surgical placement and surface roughness of the control and treated samples (Burgess et al. 1998) were equivalent. We are not aware of another study in which quantitative HA crystallinity has been isolated as the only variable that could affect the osseointegration of an HA-coated dental implant.

Although there is some evidence that a measurable amount of soluble components improves bone bonding in the earliest stages of healing, the amount and composition required, if any, has not

been determined. There does seem to be general agreement that highly crystalline coatings are more stable *in vivo* than amorphous coatings. Furthermore, the successful use of crystalline HA as a bone replacement material is well known. A review of *in vitro* and *in vivo* studies of calcium phosphate coating osseointegration is given by LeGeros (LeGeros et al. 1995).

For the present study, *in vivo* data clearly show that a coating with high HA crystallinity does not diminish the short-term osseointegration properties of plasma-sprayed HA coatings. At 3 weeks, neither group of implants was fully osseointegrated as demonstrated by the pullout data. However, this finding is not unexpected for such an early phase of healing. The 3-week timeframe was selected specifically to determine if the two coatings integrated significantly differently.

At 15 weeks osseointegration was achieved for both treated and control implants. The pullout data for control and treated samples indicate that there is no significant difference in bone attachment strength between the two coatings. The data also demonstrate that there is no increased risk for coating separation. The bone apposition data indicate that the increase in HA crystallinity does not modify the rate or degree of bone apposition to the coating surface. This is consistent with the fact that pure crystalline HA in solid form has a long clinical history in dental and orthopedic reconstructive surgery. If immediate calcium release from the coating is in fact a requirement for osseointegration, the small fraction of amorphous calcium phosphate that remains in the treated coating is apparently sufficient to accommodate this mechanism.

Histology results showing the formation of mature cortical bone and vasculature near the surface of both coatings demonstrate that the treated coating has retained the osseoconductive properties of the control coating. Qualitatively, the histology findings indicate that the treated coating has a higher *in vivo* stability when in direct contact with soft tissue. This suggests that the treated coating may provide benefit when micromotion due to loose fit prevents osseointegration, a phenomenon reported by numerous researchers (Bragdon et al. 1996; el Deeb & Holmes 1989; Goodman et al. 1994; Jasty et al. 1997). The stability of the treated coating in the presence of the resultant fibrous tissue encapsulation may allow more time for the eventual calcification of the soft tissue and osseointegration of the implant. Quantitative histological studies of control versus treated coatings in contact with fibrous tissue are needed to confirm this idea.

The results presented here provide information on the short-term *in vivo* behavior of the control and treated coatings. A long-term clinical study of the treated coating is currently underway.

Finally, the difference in dye uptake of the coatings suggests an increase in coating density imparted by the MP-1 treatment. An investigation into this potential coating densification during the process is underway.

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Résumé

La force d'intégration *in vivo* et le degré d'apposition osseuse ont été comparés pour des implants endo-osseux buccaux avec différents revêtements d'hydroxyapatite plasma-spray (HA). Les mesures de force d'excavation et l'analyse histologique ont été utilisées pour comparer deux revêtements différents accessibles commercialement chez le même fabricant. Un revêtement n'a pas reçu de traitement post-plasma-spay et contenait 75% d'HA pur. L'autre revêtement a été traité par le procédé MP-1™, un processus post-plasma-spray hydrothermal pressurisé, lequel augmente la composition du revêtement à approximativement 95% de HA pur sans changer la force d'adhésion ou de cohésion du revêtement. Les comparaisons ont été faites sur des chiens après des temps de guérison de trois et quinze semaines dans la mandibule. Aucune différence significative n'a été trouvée entre les différents types d'implants. Deux méthodes différentes ont été utilisées pour déterminer le degré d'apposition osseuse à quinze semaines. Les deux méthodes ont confirmé que le traitement MP-1 n'affectait pas le taux d'ostéointégration des revêtements HA plasma-spray. Les données histologiques qualitatives suggèrent que le revêtement traité est plus stable que le contrôle, spécialement dans les cas d'attache directe du tissu mou à l'implant. La dissolution importante des composantes phosphate de calcium dans le tissu avoisinant n'est pas nécessairement un signe avant-coureur de l'apposition directe d'os sur les implants recouverts d'HA.

Zusammenfassung

Bei oralen Implantaten mit verschiedenen plasmabeschichteten Hydroxylapatitoberflächen (HA) wurde die *in vivo* Integrationsfestigkeit und der Grad an Knochenapposition verglichen. Um zwei auf dem Market erhältliche Beschichtungen vom selben Hersteller zu vergleichen, wurden Messungen der Abreisswiderstände und histologische Analysen durchgeführt. Eine der Beschichtungen erhielt nach der Plasmabeschichtung keine Nachbehandlung und enthält etwa 75% kristallinen HA. Die andere Beschichtung wurde mit dem MP-1® Verfahren behandelt. Dabei handelt es sich um ein hydrothermales post-plasma-spray Ueberdruckverfahren, welches den Anteil an kristallinem HA in der Beschichtung auf etwa 95% erhöht ohne dabei die adhäsive und kohäsive Stärke der Beschichtung zu beeinflussen. Die Untersuchungen wurden nach einer Einheilzeit von 3 und 15 Wochen im Unterkiefer von Hunden durchgeführt. Dabei konnten keine signifikanten Unterschiede zwischen den zwei Beschichtungen gefunden werden. Zwei verschiedene Methoden wurden angewendet, um die Knochenapposition nach 15 Wo-

chen zu bestimmen. Beide Methoden bestätigten, dass das MP-1® Verfahren die Osseointegrationsrate der plasmabeschichteten HA-Oberflächen in keiner Weise beeinflusst. Qualitative histologische Untersuchungsergebnisse lassen vermuten, dass die behandelten Oberflächenbeschichtungen stabiler sind als die Kontrollbeschichtungen, speziell in Situationen, bei denen ein direkter Kontrakt zwischen Weichgewebe und Implantat besteht. Die vorliegenden Daten lassen vermuten, dass eine ausgeprägte Auflösung von Kalziumphosphatkomponenten in die umgebenden Gewebe keine unbedingt nötige Voraussetzung für die direkte Apposition von Knochen auf HA-beschichteten Implantaten darstellt.

Resumen

Se comparó la fuerza de integración en vivo y el grado de aposición ósea para implantes endooseos con cubiertas diferentes de espolvoreado de plasma de hidroxiapatita (HA). Se usaron las medidas de la fuerza de extracción y análisis histológico para comparar dos tipos diferentes de cubierta disponibles comercialmente del mismo fabricante. Una cubierta no recibe un tratamiento de post-espolvoreado de plasma y contiene alrededor de un 75% de HA cristalina. La otra cubierta se ha tratado con el procedimiento MP-1™, un proceso hidrotermal presurizado post-espolvoreado de plasma, que aumenta la composición de la cubierta en un 95% aproximadamente de HA cristalina sin cambiar la fuerza adhesiva o cohesiva de la cubierta. Se realizaron comparaciones en perros tras periodos de cicatrización de 3 y 15 semanas en la mandíbula. No se encontraron diferencias en ningún caso entre las dos cubiertas. Se usaron dos métodos diferentes para determinar el grado de aposición a las 15 semanas. Ambos métodos confirmaron que el proceso MP-1™ no afecta el índice de osteointegración de las cubiertas espolvoreadas de plasma de HA. Los datos de la histología cualitativa sugieren que la cubierta tratada es mas estable que la cubierta de control, especialmente en los casos de unión de tejido blando al implante. Los datos actuales sugieren que una extensa disolución de componentes de fosfato cálcico a los tejidos circundantes no es un precursor necesario para aposición directa de hueso a implantes cubiertos por HA.

要旨

異なるプラズマ溶射 hydroxylapatite (HA) コーティングを施した口腔骨内インプラントについて、in vivo での統合の強度と骨添加の程度を比較した。引き抜き強度の測定と組織学的分析を用いて、同一メーカーにより市販されている２種類の異なるコーティングを比較した。一方のコーティングは post-plasma-spray 処理をせず、約７５％の結晶ＨＡを含んでいる。他方のコーティングは加圧式熱水 post-plasma-spray、ＭＰ－１で処理され、コーティングの接着力あるいは凝集力の強度は不変だが、コーティングの組成は結晶ＨＡが約９５％に増加した。犬の下顎で、３週及び１５週間の治癒期間後に比較を行った。２種類のコーティング間にいずれも有意差は認められなかった。１５週後の骨添加の程度を測定するため、二つの異なる方法を用いた。両方法ともＭＰ－１処理は、プラズマ溶射ＨＡコーティングの骨性統合の率に影響を及ぼさないことを確認した。定性的組織学的データは、処理したコーティングは、特にインプラントに軟組織が直接付着している場合に、対照のコーティングより安定していることを示した。本データは、周辺組織への燐酸カルシウムの多大な溶出はＨＡコーティングされたインプラントに骨が直接添加するのに必要な前駆段階ではないことを示唆している。

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