Application of Titanium for implant-retained suprastructures

Part 1: General Aspects

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Intoduction

Titanium is a relatively young material which has been produced commercially for only 50 years. Within this time, it has obtained an important position as an ideal material not only for technical applications but also for medical use.

Titanium is a material that offers high strength, low weight and high corrosion resistance. In the medical field, the importance of titanium has long been recognized because of its excellent biocompatibility. Recently titanium has increasingly been used in surgery, especially in bone surgery. For years artificial titanium- hip- and knee- joints have been implanted successfully.

Keeping the reasons for the use of titanium in mind, the interest of a dentist may be focussed on the question "why to use titanium in dentistry and especially for implant retained suprastructures?" Two aspects have to be considered and will be discussed in more detail: the first aspect is biocompatibility, and the second is biofunctionality.

Biocompatibility

Biocompatibility may be defined as safeness of a material in the biological environment. In the sense of Paracelsus, one of the forefathers of modern medicine, the German Federal Office of Health demands for dental restorations, that the number of different alloys present in the mouth of a patient should be kept at a minimum and that the number of ions released by dental alloys should be negligible from a toxicological point of view.[1]

From a practicle point of view this requires materials which are usable for a wide range of applications, also highly corrosion resistant and not releasing toxic elements.

A look on the chemical composition of pure titanium reveals, that even pure titanium is not 100% pure, but only of approximately 99,5 % purity (Fig.1). However, none of the trace elements, accompanying titanium, like iron, oxygen, hydrogen, carbon and nitrogen, has been recognized as toxic. The permissable amount of iron and oxigen depends on the grade of titanium, increasing from grade 1 to grade 4. Thus, Titanium grade 1 should be preferred for medical and dental applications, since this offers the highest purity.

From electrochemical experiments in artificial saliva, the break through potential of dental metallic materials can be derived. Plots of current density versus electric voltage show that the break through potential of titanium is superior to almost all other dental alloys used for restorations like noble gold-based alloys and base metal alloys like Co-Cr- and NiCr-alloys.

Grade	Material number	Fe_{max}	O_{max}	Chemical composition [mass %]			
				N_{max}	C_{max}	H_{max}	TI
Ti 1	3.7025	0,15	0,12	0,05	0,06	0,013	Bal. 99,5% Ti
Ti 2	3.7035	0,20	0,18	0,05	0,06	0,013	Bal. 99,5% Ti
Ti 3	3.7055	0,25	0,25	0,05	0,06	0,013	Bal. 99,5% Ti
Ti 4	3.7065	0,30	0,35	0,05	0,06	0,013	Bal. 99,5% Ti

Fig. 1: Chemical composition of pure titanium according to DIN 17850

There is a correlation between Corrosion resistance and biocompatibility of metals and alloys. Not only corrosion reaction but also the toxic potential of a metal influences biocompatibility. Pure copper or nickel are known as low corrrosion resistant and being toxic. Both offer a poor biocompatibility. On the other side, titanium is classified as a highly biocompatible material which has vital interaction with the biological environment without toxic effects.

Informations about biological response to a material can be obtained by implantation tests. Investigating the degree of connective tissue encapsulation. reveals information about toxicity.

Results of intramuscular implantation tests reveal that there is nearly no reaction of the tissue to titanium. Significant higher degrees of reactions have been found for other dental alloy systems. A Beryllium-containing Ni based alloy showed the highest observed reaction (Fig.2).[2]

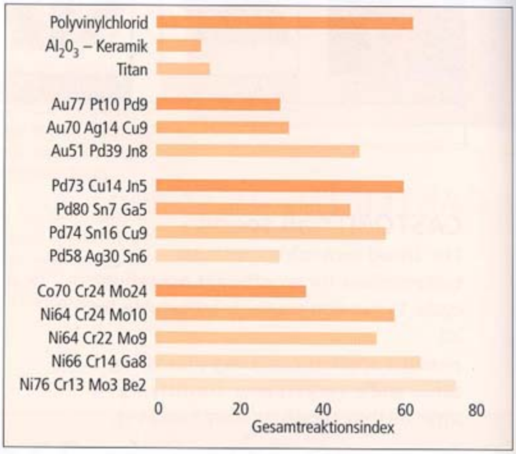

Fig. 2: Results of intramuscular implantation-test (2)

Similar results have been obtained from subcutanious implantation tests. Again, titanium exhibits the lowest thickness of connective tissue, indicating excellent biocompatibility.

Biofunctionality

Suitability of a material for a dental application does not only depend on biocompatibilty, but biofunctionality also must to be considered.

This term may be defined as the ability of fulfilling the intended purpose in the biological environment. Of course, the suitability for a suprastructure, placed on an implant in the mouth is of most interest in the context of this paper.

The mechanical properties of cast pure titanium indicate, that titanium has sufficient mechanical strength to withstand physiological forces in the oral environment (Fig.3). Following the standardized classification of dental materials for fixed restorations, cast titanium is a class 4-material.

Yield Strength $R_{p\,0,2}$ (MPa)	460
Tensile Strength R_m (MPa)	600
Young-Modulus (GPa)	110
Vickers Hardness (HV 10)	200
Elongation (A_5)	12
Type	4

Fig. 3: Mechanical properties of pure titanium (as cast)

Class 4 means, that it is suitable for applications subject to very high stress, for example veneered single crowns, wide-span-bridges or bridges with small cross-sections, bars, attachments, and implant-retained suprastructures.

Apart from its mechanical strength, titanium has a number of other properties which make it favorable for use in dentistry.

One of these is its low density which makes the restoration extremely light. With a density of 4.5 g/cm^3, titanium is the metal which marks the transition from light metals to the so-called heavy metals.

Its high melting point is a property, that is more linked to processing in the dental lab.

Therefore, it may be mentioned here only, that this results in a high thermal stability during porcelain-fusing-process without deformation.

A further important property is its low thermal conductivity (Fig.4). In alloys based on Nickel and Cobalt, it is already significantly lower than in gold alloys. However, titanium is even less conductive and therefore reduces even further thermally induced irritation of the pulp. Even in model casting structures with large surface areas, the ability of titanium to dampen the effect of heat or cold is of immediate benefit to the patient.

Metal	Thermoconductivity $[Wm^{-1}\,k^{-1}]$
Gold	297
Nickel	92
Cobalt	71
Titanium	22
Enamel*	1,5–1,76
Dentin*	0,99–1,87

Fig. 4: Thermo-conductivity of metals

From a diagnostic point of view, the transparency of titanium to x-rays is particularly useful:

In the case of a gold alloy suprastructure, as in this radiograph, the absorption of x-rays is considerably higher, which also means that it is impossible to x-ray a tooth with a gold crown, at least not with a dose that should be administered to a patient. However,it can be seen that the titanium implants are radiotransparent.

Absorption of x-rays is proportional to the 4. power of the ordinal number, taken from the periodic table of elements. For that reason, radiotransparency of titanium is 166 times higher than of gold.

The good radiotransparency does not only enable the dentist for example to detect secondary caries without removing the crown, but also the dental technician to control the quality of his castings.

Aesthetic appearence of titanium crowns and bridges of course depends on veneering. A final important aspect, regarding properties of titanium, therefore is that of veneering titanium with ceramics.

Titanium has a very low coefficient of thermal expansion in relation to the known porcelain-fused-to-metal- alloys.

Conventional dental porcelains cannot be used for veneering titanium, because they do not fit to its very low coefficient of thermal expansion. However, ceramics specially adopted for titanium are available today.

Titanium is known to have a high affinity to oxigen. From an biological point of view, this leads to the formation of passive layers on the surface, contributing to good biocompatibility. During porcelain firing, high affinity to oxigen is most undesirable. Therefore the titanium surface is sealed with a special bonder in the first bake.

For dental metal ceramic restorative systems, there exists a standard-requirement for a minimum bond strength according to the 3-point-bending-test of 25 MPa.

Best results according to this test show values of 42 MPa,[3] this is equal to other clinically proven metal-ceramic-systems (Fig. 5).

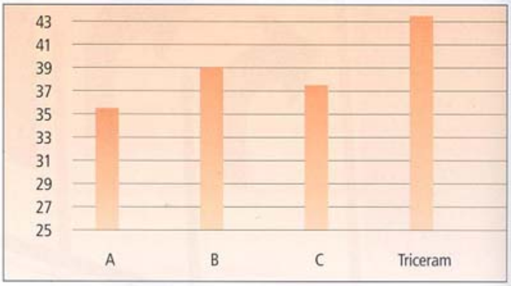

Fig.5: Debonding/crack-initiation strength (DIN EN ISO 9693), titanium ceramics (3)

Not only high metal-ceramic- bond strength can be achieved with a high end titanium ceramic, but also a high grade of aesthetics (Fig.6).

Fig.6: Single anterior crowns, titanium (Tritan), veneered with Triceram®,Esprident

The "all in Titanium" concept

Considering the properties of titanium, that have been mentioned, it may be not unexpected, that Titanium is estimated to be a restorative material suitable for most clinical indications. In addition, almost all dental implants are made from titanium or titanium based alloys. Therefore, it is most consistent also to use titanium for implant-retained suprastructures, following the conception "all in one metal: all in titanium." Compared with gold-based and CoCr-based alloys, titanium shows the most pronounced aptitude for different dental prosthetic applications and is the most suitable for implant suprastructures (Fig.7)[4], since using titanium avoids metal-induced osseodesintegration. Considering the situation of combined dentures, it is obvious that the use of the same material is effective in avoiding adverse effects due to different electric potentials, that may arise from the use of different materials.[5] Due to the build-up of the electric potential not only corrosion may occur but also electric shocks or metal taste may be reported from the patient. The use of titanium is able to avoid all these effects and to give even the most sensitive patients a reliably cure.

Indication	Titanium	Co-base	Au-base
Inlays	+	--	++
Full Crowns	++	+	++
Veneered Crowns	++	++	++
Bridges	++	++	++
Adhesive Bridges	+	++	--
R.P. D. with clasps	++	++	--
Proth. with attachments/bars	++	++	+
Proth. with telescopic crowns	++	++	+
Implant-retained suprastructures	++	+	+
Endodontic pins	++	+	++
	18	15	13

Fig.7: Aptitude for dental prosthetic applications (acc. to Lenz (4))

Nowadays, also prefabricated parts, made from titanium, are available for a good implant system, specially adapted to the system and exhibiting high precision (Fig.8).

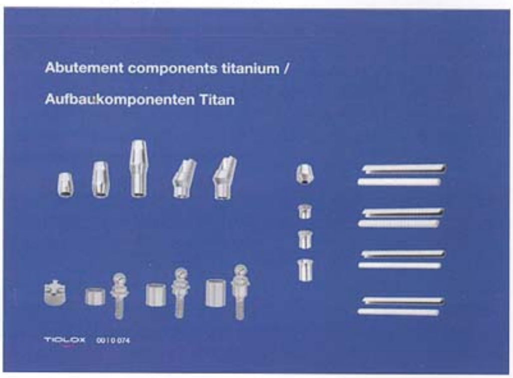

Fig. 8: Abutment components, titanium (Tiolox®)

Prefabricated parts, combined with individual castings combine precision and flexibility of design for titanium suprastructures (Fig.9)

Prefabricated titanium bars, bar sleeves, retainers and prefabricated conical titanium abutments can be joint by laserwelding to a restoration, made from titanium even without any casting, resulting in a precise, cost effective restoration (Fig.10).

Laserwelding

Prefabricated parts can easily to be fixed by using the laser-welding-technology.

A comparison of three different joining-techniques reveals, why laserwelding is the recommended method for joining titanium. Solders for titanium, used for technical appications, do not fulfill medical requirements regarding biocompatibility and corrosion resistance due to a composition of 70% Ti, 20% Pd and 10% Cu for example.

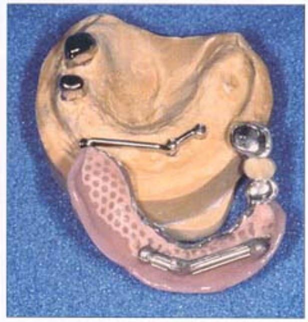

Fig. 9: Telescopic crowns, connecting bars, titanium

Fig. 10: Prefabricated titanium abutments (Tiolox®), bars, bar sleeve, retainer, all laser-welded.

Plasma-welding generates large areas affected by heat, this results in high deformation of welding parts

Instead of thas, only laserwelding creates biocompatible joints. Only small areas are affected by heat, this results in low deformation.

Laser-welds are as strong as cast material, therefore laserwelding does not create any weak area like soldering. With laser-welding, a precise, passive fit of implant-retained suprastructures can be obtained.

Prefabricated titanium bars, bar sleeves, retainers and prefabricated conical titanium abutments can be joint by laserwelding to a restoration, made from titanium even without any casting, resulting in a precise, cost effective restoration.

Summary

Titanium is the ideal dental restorative material, not only but also for implant-retained suprastructures, because it is biocompatible, suitable for a wide range of applications, permits high precision and fulfills highest aesthetic demands.

Bibliography

1. BUNDESGESUNDHEITSAMT, Empfehlungen zur Risikominimierung bei der Auswahl und Verarbeitung von zahnärztlichen Gußlegierungen/Dentalloten und kieferorthopädisch verwendeten Legierungen, Berlin, 1993
2. REULING,N.: Biologische Verträglichkeit von Dentallegierungen, in: SIEBERT,G.:Dentallegierungen in der zahnärztlichen Prothetik, Carl Hanser
3. PRAUD, C., Apport de la ceramique Triceram a la realisation de prothese ceramo metalliques sur titan, Ph.D. Thesis, Universite de Nantes, 1999
4. LENZ, E.: Titan als prothetischer Werkstoff, ZMK 6, 1999
5. LACEFIELD, W.R. : Materials characteristics of uncouted/ceramic coated implant materials, Adv Dent Res 13: 21-26, June 1999