Rapid Communication

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A comparative morphological study of titanium dioxide surface layer dental implants

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Abstract: Most dental implants used in dental practices are made of titanium or titanium alloys so that the essential differences promoted by the various manufacturers are at the level of their surface; through specific surface treatments, the aim is to obtain improved results regarding osseointegration. This study attempts to identify the differences between a series of used brands of dental implants by analyzing the chemical composition and the morphology of their surface and is particularly significant for the potential users as it highlights the manner of performances of the

aforementioned implants, providing them with a tool in choosing the proper dental implant to suit their needs. It was found that, as the technology evolved and the costs were reduced, there is a net preference for using pure titanium or its alloys in the manufacture of dental implants versus the stainless steel titanium alloys, considered now a thing of the past.

Keywords: dental materials, implants surface, surface analysis

1 Introduction

A significant number of researchers sought to identify over the time a number of biocompatible materials which can be used to replace and/or restore the missing or injured anatomical structures. It is considered that a material must meet at least three conditions in order to be used for implantation: to be biocompatible, to have a balance of physical and mechanical properties so that it performs as expected, and the medical device should be relatively easy to produce in large volumes, to the same standard [1].

Biotolerant materials (Co–Cr alloys, stainless steel, tantalum, or some polyols), bioinert materials (titanium and its alloys, zirconia), or even bioactive materials (hydroxyapatite) have been identified, but the constraints due to the small size of devices and the increased mechanical stress they are subjected to led over the time to a preference for bioinert materials such as titanium and its alloys, which have proven to represent an optimal solution for dental implants. Their enhanced biocompatibility and other desired properties and qualities made the manufacturers to choose titanium and its alloys as raw materials for dental implants over the stainless steel titanium alloys [2–15]. Titanium reacts with many other chemical elements (Ag, Al, V, Zn etc.) to form alloys. The American Society for Testing and Materials organized titanium and its alloys on a scale of 1–39. The first four grades are of pure (non-alloy) titanium types and the others for alloys. The alloys are organized

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into three broad categories, Alpha, Alpha Beta, and Beta, and their characteristics, properties, preferences, and uses differ widely based on the particular type of alloy chosen [14–23]. Alpha alloys are most commonly made of aluminum and tin, which makes them ductile, with high hardness, gives them good mechanical properties at low temperatures, has the highest corrosion resistance, cannot be forged at high temperatures, but they can be welded. Alpha Beta alloys are more durable, but Alpha alloys are strong enough to make them a preferred choice in chemical or aeronautical equipment. Beta alloys have medium to high hardness, can be forged or processed at high temperatures, they are weldable, and are used in aeronautics, in the development of prosthetic elements, and in marine equipment. Their elevated density makes them particularly suitable for the production of certain parts which must maintain their shape and structure even at the highest pressures.

Titanium Grade 2, Titanium Grade 4, and Ti6Al4V-ELI alloy (Titanium Grade 23) are the most widely used materials in the production of dental implants [15]. In Table 1, a comparison of the technical data of these raw materials [2,3,15], namely, the chemical composition and the associated physical characteristics for the aforementioned materials, is presented.

It can be observed that the values for fracture toughness are close for TiCP4 to Ti6Al4V-ELI alloy (Ti Grade 23). The metallographic analysis reveals the lack of homogeneity in the titanium alloys [20]: the presence of alloying elements can induce microscopic defects. Last but not least, the reactivity to the ambient temperature of titanium

with oxygen is important. The formation of a TiO₂ layer on the surface of titanium and titanium alloys cannot be avoided; this layer forms spontaneously, upon contact with oxygen from atmospheric air [4,5,21,22].

2 Materials and methods

In this research, we compared a Dentix SLA implant (sample 10) as well as a Dentix Nano implant (sample 11), produced by the company Dentix Millennium in Romania with nine other implants from well-known reputable manufacturers of dental implants, purchased, and sealed in the original packaging from local distributors (Adin, Alpha-Bio, Ankylos, Israel OEM, Megagen, Nobel Biocare, Osstem, Ritter, Straumann, Zimmer) randomly named from S1 to S9. All the samples were subjected to electron microscopy investigations. In order to limit the variable to a minimum possible, all the investigated implants had a diameter between 4.0 and 4.3 mm and a length between 12.5 and 13 mm. The average surface area of these implants, measured on the 3D model, was 209.2486 mm². This surface area is increased by the processes of roughness modification. The morphological characterization of samples was carried out using scanning electron microscopy (SEM) with an FEI Inspect S50 apparatus (FEI, Hillsboro, OR, USA), used with energy-dispersive X-ray spectroscopy (EDS) system produced by EDAX (Mahwah, NJ 07430, USA), with fixed silicon detector and Peltier element integrated as a cooling system. The SEM analyses were performed at an acceleration voltage of 20–30 kV, in the magnification range of 50–50,000×, at the working distance of 10 cm, with a spot beam 2. For EDS, the beam spot used was 5.5–6, the working distance was 10 cm, and the dead time was 33. Prior to microscope insertion and visualization, the samples were washed in isopropyl alcohol and then rinsed with double distilled water. A scratch was made on the surface of each dental implant, in order to detect the differences in composition between the treated surface of the implant and its interior.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and discussion

The results of the samples examined under the electron microscope, their surface morphology, the associated chemical composition, and the corresponding SEM images are presented in Figures 1–12.

Table 1: Chemical composition and physical characteristics of TiCP2, TiCP4, and Ti6Al4V-ELI (Ti Grade 23)

	Ti Grade 2	Ti Grade 4	Ti6Al4V-ELI
Maximum content of Al	—	—	5.5–6.5%
Maximum content of V	—	—	3.5–4.5%
Maximum content of C	0.08%	0.08%	0.08%
Maximum content of N	0.03%	0.05%	0.05%
Maximum content of O	0.25%	0.4%	0.13%
Maximum content of Fe	0.3%	0.5%	0.25%
Maximum content of H	0.015%	0.015%	0.012%
Maximum content of other elements in total	0.4%	0.4%	0.4%
Minimum content of Ti	98.825%	98.455%	88.078%
Density (g/cm ³)	4.51	4.51	4.42
Elasticity modulus (GPa)	103–107	105	105–116
Melting point (C)	1,665	1,660	1,655
Fracture toughness (MPa)	66	99–140	100
Shear modulus (GPa)	45	40	44

Figure 1 shows the image of sample S1 at a magnification of 20k $\times$. At magnifications of 200 $\times$, 1,000 $\times$ we observe the uniform appearance, with fine structure of holes on the surface of the material, with an appearance similar to the surface corroded with acid. The surface, analyzed in detail, has a certain degree of roughness, its appearance changing from uneven wells, with thin, irregular, corroded (5,000 $\times$) wells and walls toward ridges and concavities of different shapes with several microns, 1–4 μm in the image. Similar results were found with other implants with their surface sample treated with acids, presented in detailed images (20,000 $\times$), where deep and lacy pores with diameters of 3–5 μm can be noticed. In Figure 2, the surface treatment originally applied to sample S2 ensured a homogeneous,

Figure 3: SEM image of sample S3 at a magnification of 20k $\times$.

Figure 1: SEM image of sample S1 at a magnification of 20k $\times$.

Figure 4: SEM image of sample S4 at a magnification of 20k $\times$.

Figure 2: SEM image of sample S2 at a magnification of 20k $\times$.

Figure 5: SEM image of sample S5 at a magnification of 20k $\times$.

Figure 6: SEM image of sample S6 at a magnification of 20k $\times$.

Figure 9: SEM image of sample S9 at a magnification of 20k $\times$.

Figure 7: SEM image of sample S7 at a magnification of 20k $\times$.

Figure 8: SEM image of sample S8 at a magnification of 20k $\times$.

Figure 10: SEM image of sample S10 at a magnification of 5k $\times$.

abrasive appearance throughout the implant. At 2,000 $\times$, there are rounded honeycomb-type alveoli in characteristic assemblies with an appearance similar to the acid-corroded surface. At higher magnifications (20,000 $\times$), the rounded alveoli have the appearance of deep pores with diameters of 1.5–3 microns, some joined, rounded but irregular, with unevenly corroded walls. Figure 3 shows the image of sample S3 at a magnification of 20k $\times$. At magnifications over 1,000, the investigated implant presents a relatively uneven, flattened appearance, a structure with ridges and valleys, resembling a honeycomb, consisting of asperities, grains, and pores (5,000 $\times$) of 1–2 microns, circular (image 20k $\times$), sometimes rectangular. Figure 4 shows the image of sample S4 at 20k $\times$ magnification. The SEM image at low magnification (200 $\times$) indicates a uniform appearance of the implant, with dunes

Figure 11: SEM image of sample S11 at a magnification of 5k $\times$.

Figure 12: SEM image of sample S11 at a magnification of 20k $\times$.

between 10 and 20 μm , with small grains. At higher magnifications (5,000 $\times$), the corrugated relief, sand dune type, is preserved, noticing concavities of 10–18 μm in diameter, with irregular holes and fine grains, of lengths of $\sim 1 \mu\text{m}$ (20,000 $\times$), stuck in the walls of the recesses. The surface type looks similar to acid corroded surface (SLA). In Figure 5, the SEM analysis at 20k $\times$ magnification shows simple (0) and joined (double – 8/ ∞) tubular cylindrical structures, rarely triple, with depth aspect, with outer diameters 4–5 microns and inner diameters 1.5 to 2 microns. Distinct deep tubular pores with walls ~ 2 microns in diameter. On the implant analyzed the ratio of enlarged tubes/pore surface (shorter tubes) is about 1:1. In Figure 6, the appearance of this dental implant is characteristic of the two treatments to which it was

sampleably subjected: sand blasting and acid corrosion (SLA): rough relief, with craters, irregular inclusions, grooves (200 $\times$ and 2,000 $\times$), all generating an expanded surface for easier cell attachment. In detail, we can distinguish inclusions of different angular and/or semi-rounded shapes and micron grains embedded in the irregular, uneven surface, full of pores (200 $\times$, 5,000 $\times$, 20,000 $\times$) of various diameters (0.5–4 μm). Figure 7 shows the image of S7 sample at a magnification of 20k $\times$. Observed at low magnifications (200 $\times$), the surface of this implant has a similar appearance to the blast. Furthermore, at 2,000 $\times$ the unevenly corroded appearance becomes visible, with untouched areas (with a size of 1–20 microns) juxtaposed with the corroded ones. Going forward with the enlargement of the images (5,000 $\times$), the structure is revealed as very porous, attacked deeper, consisting of islands of uncorroded material between relatively circular depths with attacked walls, full of formations sampleably given by the corrosion with the acids used in the treatment. The rough structure is spread from depressions of 15–30 microns (2,000 $\times$) to the finest pores, even submicron (20,000 $\times$), of different sizes. In Figure 8, it is observed that this dental implant presents a continuous appearance with rounded alveolar structures (1.7–2.5 microns). Figure 9 shows the SEM image at 20k $\times$ of sample S9. The surface is characterized by a slightly rough, smooth, homogeneous appearance, with periods of $\sim 10 \mu\text{m}$ (200 $\times$ and 1,000 $\times$). The extended surface has numerous, relatively flattened edges. In detail, a rugged, rocky structure (2,000 $\times$ and 5,000 $\times$) is highlighted. A topography cauliflower-like is also distinguished. At 20,000 magnifications, the material appears loose, with pores of approximately 1 micron or submicron. Figure 10 shows the image of S10 sample (Dentix Nano implant) at a magnification of 20k $\times$. The TiO_2 nanostructure can be seen all over the surface, covering the Ti microstructure. The TiO_2 nanostructure is composed of a layer of TiO_2 nanotubes, perpendicularly oriented on the implant surface. The TiO_2 nanotubes on the surface of the Dentix Nano implant have an average of 100–200 nm in height, 60–80 nm outer diameter, 40–60 nm inner diameter, and 10–15 nm wall thickness.

The EDS analysis also provides a graphical representation of the peaks of the spectra emitted by the various chemical elements in the composition of all samples analyzed. In Figures 13 and 14, one may see two representative graphs for sample S4 and sample S6 depicting the elements with highest mass percentages. For sample S4, in Figure 13, the graph shows the highest mass percentage for titanium, which was expected, followed by oxygen, a direct proof of titanium dioxide formation, followed by vanadium and aluminum, confirming the existence of

Figure 13: EDS of sample S4.

Figure 14: EDS of sample S6.

the alloying elements and traces of carbon, iron, and chlorine.

Figure 14 corresponding to EDS for sample S6 shows also the highest peak for titanium, followed by oxygen and high values for aluminum and vanadium; one may also notice the presence, besides carbon and iron of

copper; as different manufacturers use different alloy compositions, this technique may be used as a useful tool in differentiating between two very similar implants and making correlations also between the chemical surface composition and their osseointegration behavior.

The results of EDS investigations for S1–S11 samples and the interpretations associated with these analyses are presented in Table 2.

Most dental implants have surfaces with similar morphology; the roughness is between 1 and 10 μm , and their appearance is specific to the surfaces obtained by acid attack (19) in the SLA-type surface treatment – treatment that has already confirmed its performance in the decades since it is used. Some of the manufacturers, who tried to differentiate by applying anodizing techniques, obtained surfaces with different appearance, showing craters instead of acid corrosion wells or fields of nanotubes. The presence of TiO_2 nanotube layer increases the surface area exposed to the body fluids by six times, offering increased potential for body response and bone integration. The TiO_2 nanotubes on the surface of the Dentix Nano implants have an average of 100–200 nm in height, 60–80 nm outer diameter, 40–60 nm inner diameter, and 10–15 nm wall thickness. The nanotubes cover the entire surface of the implant, being joined together, like a honeycomb. The ratio between the inner surface of the cylinder and that covered by a nanotube is (the average values were used) as follows:

$$\begin{aligned} &150 \times 50 \text{ nm} \times 3.14 / (70 \times 70 \text{ nm}) / 4 \times 3.14 \\ &= 23,550 \text{ nm}^2 / 3846.5 \text{ nm}^2 = 6.12. \end{aligned}$$

The chemical composition of the materials from which dental implants are made must be analyzed in the context of the homogeneity of the respective material. If the raw material is not homogeneous, dental implants, being a very small device (a medium-sized implant – $4.2 \times 11 \text{ mm}$, weighs 0.4 g), may end up having marginally different chemical compositions, even if they come from the same bar of raw material with potential repercussions on the behavior from the mechanical point of view, e.g., fatigue resistance and/or microbial-induced corrosion resistance. This is an additional reason for using pure titanium instead of titanium alloys, thereby reducing the effects of compositional non-homogeneities, as well as the creation of a localized galvanic reaction that can induce galvanic corrosion. The phenomenon of fracture of dental implants is quite rare [18]. The percentage of implants that fracture in the initial stages (at insertion or in the first days) is about 1% after some authors [6], but we consider this figure to be too high. The mechanical

Table 2: EDS compositional analysis of the studied samples

Sample	EDS analysis results				Description
	Surface element	Weight (%)	Atomic (%)	Error (%)	
S1	C K	0.00	0.00	99.99	EDS analysis indicates a titanium majority implant (67.91% mass, 43.55% atomic), with an important contribution of oxygen (predictable on the surface of oxidized titanium layer, on the surface, 27.64% mass, 53.26% atomic) and a significant calcium content (3.48%, 2.67% atomic). Treatment of this type of implant involves an extremely fine layer (monoatomic, most likely) of Ca, in order to improve the osseointegration
	O K	27.74	53.26	10.54	
	Ca K	3.48	2.67	3.07	
	Ti K	67.91	43.55	1.39	
	V K	0.86	0.52	5.08	
S2	C K	0.13	0.44	14.13	Titanium appears to be the only major chemical constituent of this implant (89.30% mass, 73.51% atomic) in quantifying EDS, next to oxygen (10.57% mass, 26.05% atomic), of which we can assume that it exists only in the oxidized layer from the surface. Carbon sampleably appears as a contaminant. In contrast, the compositional analysis in the scratch has fine traces of calcium (0.14% atomic), aluminum (0.12%), and silicon (1.51% atomic), sampleably due to the surface treatment with the processing substances
	O K	10.57	26.05	10.58	
	Ti K	89.30	73.51	1.31	
S3	O K	14.55	34.51	10.73	The EDS compositional analysis confirms a titanium alloy (80–85% by mass) with zirconium (6–5% by mass) and the remaining oxygen
	Al K	0.08	0.11	21.35	
	Zr L	6.02	2.51	1.91	
	Ti K	89.30	73.51	1.31	
S4	C K	2.96	8.47	9.12	EDS analysis confirms Ti–Al–V alloy (Titan Grade 5) as a material of this dental implant: Ti 73.11, Al 3.66, V 5.58, in mass percentages. Iron (0.40% by mass) and carbon (2.96% by mass) are also present as a trace and as a minority element. On the scratched surface, the more the scratch is very fine, the ratio of the elements is about the same. The difference consists only in a larger amount of oxygen in the scratch (21.62%, compared to 14.10% by mass)
	N K	0.00	0.00	7.76	
	O K	14.10	30.27	11.18	
	Al K	3.66	4.66	6.70	
	Cl K	0.18	0.18	15.80	
	Ti K	73.11	52.41	1.36	
	V K	5.58	3.76	2.53	
	Fe K	0.40	0.25	22.45	
S5	O K		33.11		EDS analysis indicates an implant based on pure, oxidized titanium (most likely on the surface: 66.09% atomic Ti with 33.11% atomic O, on the surface, respectively, ~74% atomic Ti with 25.2% atomic O). The difference in oxygen between the implant surface and the inside (scratch) may suggest that the tubular structures on the surface, removed in the case of scratches, are those that contain more oxygen, in accordance with the structure declared by the manufacturer, anodized titanium, with titanium dioxide and phosphorus
	Ti K		66.09		
S6	C K	0.04	0.10	72.63	EDS analysis shows the implant is made of Ti–Al–V alloy: in mass percent Ti 58.31, Al 8.32, V 4.83. Significant amount of oxygen, 28.28% by mass, 51.95% atomic, indicates the oxidation and passivation of the titanium support. There are also fine traces of iron (0.16% atomic), possibly also carbon and copper (below 0.04% atomic, with an error margin over 50%)
	N K	0.00	0.00	8.97	
	O K	28.18	51.95	10.46	
	Al K	8.32	9.09	6.07	
	Ti K	58.31	35.90	1.37	
	V K	4.83	2.97	2.54	
	Fe K	0.30	0.16	18.04	
	Cu K	0.02	0.01	58.11	
S7	C K	1.15	3.50	9.64	EDS analysis indicates a titanium alloy based on Al and V as the implant material. Unexpectedly, the content of V (5.2–6.8% by mass) seems to be higher than that of Al (~4% by mass). The phenomenon of surface oxidation (passivation) is also highlighted by the significant oxygen content (~12.3% by mass), both on its surface and in the applied scratches. On the surface, the sample also suffered a slight carbon contamination (1.15% mass, 3.50% atomic), most likely accidental. Fine traces of Fe and Cu are also distinguished
	N K	0.00	0.00	6.92	
	O K	12.32	28.21	10.94	
	Al K	4.02	5.46	6.39	
	Ti K	76.98	58.89	1.31	
	V K	5.18	3.72	2.08	
	Cu K	0.35	0.20	9.44	
S8	O K	7.52	19.56	11.80	EDS analysis shows mostly titanium content (91.89% mass, 79.79% atomic per thread), without other alloying elements, with incorporated
	Al K	0.03	0.05	66.31	

Table 2: Continued

Sample	EDS analysis results				Description
	Surface element	Weight (%)	Atomic (%)	Error (%)	
S9	Si K	0.05	0.08	60.26	oxygen (7.52% mass, respectively, 19.56% atomic) and traces of Ca (0.50%), only on the surface. The titanium percentage increases and the oxygen decreases in the scratch, as the scratch deepens, as the biocompatible layer of TiO ₂ forms at the surface
	Ca K	0.50	0.52	6.22	
	Ti K	91.89	79.79	1.33	
	C K	0.00	0.00	99.99	EDS analysis applied to the OEM implant indicates that it is made of Ti–Al–V (mass percentages: Ti 64.02; Al 7.94; V 4.92). The compositional percentages differ from the Ti Grade 5 alloy recipe, most sampleably due to the fact that passivation oxygen appears from the implant surface (21.47% by mass) and elements specific to the surface treatment (And sampleably by the blasting process 0.04% by mass, possible as 0.35%) as well as possible contaminants (Cl, Fe, Ni, Cu, W). The traces of iron, nickel, and copper can come from the composition of the alloy. The relatively high percentage of Al could come from blasting with alumina particles
	O K	21.47	43.28	10.50	
	Na K	0.00	0.00	99.99	
	Mg K	0.00	0.00	99.99	
	Al K	7.94	9.49	6.17	
	Si K	0.04	0.05	43.89	
	Ca K	0.35	0.28	8.09	
	Ti K	64.02	43.11	1.37	
	V K	4.92	3.11	2.21	
	Fe K	0.94	0.54	8.37	
	Ni K	0.05	0.03	57.84	
	Cu K	0.15	0.08	38.96	
	W L	0.12	0.02	56.20	
S10	Ti K	99.83	99.85	1.15	EDS analysis indicates that the Dentix SLA implant is made of pure titanium (99.83% mass percentage), without alloying elements. The presence of iron is lower than that declared by the producer of the raw material
	Fe K	0.17	0.15	44.63	
S11	O K	20.85	43.72	11.18	EDS analysis shows that the Dentix Nano implant is made of pure titanium, without any other alloying elements. Aluminum and silicon are sampleably derived from the blasting material, and the iron is below the limits declared by the raw material manufacturer. The oxygen is present in a high concentration, above the average of the compared implants, demonstrating the abundance of the nanostructured layer of TiO ₂
	Al K	1.52	1.89	8.72	
	Si K	0.06	0.08	45.69	
	Ti K	77.39	54.20	1.18	
	Fe K	0.18	0.11	31.83	

properties of the least resistant material (Ti Grade 2 and Ti Grade 4) are more than sufficient for the dental implants to fully respond to the proposed purpose [17], a fact demonstrated by the fatigue studies carried out by our team. The risk of fracture of dental implants is not a real reason for manufacturers to opt for one material or another. Neither osseointegration performance justifies the choice of Ti6Al4V alloy in favor of pure titanium [11]. Due to the high reactivity of titanium with oxygen, as well as surface treatment procedures, all dental implants have a layer of TiO₂ that chemically stabilizes the surface (passivation). Titanium oxide plays a protective role, preventing contact of the titanium with other chemical elements, thus explaining the corrosion resistance of this material. In fact, titanium dioxide is due to the biocompatibility of dental implants: the bone tissue comes in close contact with the TiO₂ layer, not with pure or allied titanium [12]. Recent concerns of the research departments of dental implant manufacturers are aimed

at identifying nanostructuring methods of the TiO₂ layer which, when formed spontaneously, is in an amorphous state. The nanostructuring of the TiO₂ layer will open new opportunities leading the development of medical devices to the next level. Regarding the chemical composition of the titanium and its alloys, we consider some aspects as being particularly important and which were not given the true importance: the purity and homogeneity of the material from which dental implants are produced [7] and the biological effect of the presence of the alloying chemical elements. The low purity and non-homogeneity of the material from which dental implants are produced is the main cause of their fracture. The process begins with microcracks observable under the electron microscope, microcracks that either exist in the raw material, or occur at the first mechanical exposure on the implant, due to the different resistance at different points of the piece. Even so, a number of factors are needed for a fracture to occur, and this happens when

we are dealing with a small implant, where the technology has been pushed to the limit. In our studies, we encountered fractured implants, with a size of 3.3 mm × 8 mm, at which the minimum wall thickness (where it also failed) was 60 microns. It happened that in that area, the material was not homogeneous, and thus, the accumulation of factors occurred. The biological effect of the chemical elements with which titanium alloying has been achieved is insufficiently studied. Aluminum and vanadium are not known to be chemical elements with beneficial effects on the body [8–10]. The cell viability of binary alloys (TiAl and TiV) is lower than that of pure titanium, TiCP [16]. Vanadium is cytotoxic at concentrations above 4% in alloys and neurotoxic [13]. We consider the use of vanadium too risky, given that the theoretical percentage is exactly at the limit of cytotoxicity (in Ti6Al4V, vanadium has 4%). The metallurgical procedures for obtaining titanium alloys, made on batches of tonnes, cannot have the precision of laboratory procedures, so that there is a guarantee that the vanadium level does not exceed 4% at all points in the volume of a batch. As evidence, the alloy manufacturers claim the presence of these chemical elements with ranges of values, not with exact values, and the chemical compositions presented above by EDS analysis also demonstrate different concentrations in reality. All these risks are assumed free of charge as long as the benefits are not tailored, and above all, they are not required. The increased mechanical strength of the Ti6Al4V alloy is not required, and the shortcomings that an alloy can bring can negatively offset its relative advantages. Pure materials have sufficiently good properties, and statistics do not show that pure titanium implants fracture more often than alloy implants.

4 Conclusions

Following the investigations made on the 11 dental implant samples from different providers, it emerges as a general conclusion the preference for the use of pure titanium or its alloys in the manufacture of dental implants. The most commonly used materials are Ti Grade 4 and Ti6Al4V-ELI alloy. However, there are differences from producer to producer, some manufacturers preferring custom-made alloys, by adding a certain element, such as Zr with possible positive contributions to product performance. However, only clinically conducted studies (these are costly and they stretch over the years, requiring investigations on human subjects) are able to demonstrate for good whether or not these marginal

compositional differences have a beneficial effect on the osseointegration of the implants and their durability over time. It was found that by comparing the chemical composition of the various brands of dental implants with the chemical composition of the raw materials used, it is possible to construct an image of possible contamination (most sampleably of the surface) with other elements not initially existing in the raw material, as well as of the efficiency of the cleaning processes. As far as the preference of pure titanium versus its alloys is concerned, there is no need for an increased mechanical strength of alloys, these bringing about more negative issues and offsetting its relative advantages as long as pure titanium has sufficiently good mechanical properties and better osseointegration characteristics.

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