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Dental Implant Surface: Driving Force for Successful Osseointegration

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ABSTRACT

Background: Surface characteristics have shown to influence the osseointegration property of dental implants. Surface alterations are done with an aim of providing rougher surface to induce better cell adhesion and intimate implant-to-bone contact. Aim: To analyze the surface characteristics of Indident Dental Implant system and to compare its surface properties with three commercial dental implant systems. Objective: To study the surface topography and chemical composition of four commercially available dental implant systems.
Materials and Methods: Surface characterization of four implant systems was studied using optical profilometry, scanning electron microscopy, energy dispersive X-ray spectroscopy and X-ray photoelectron spectroscopy. The analysis was done in two regions; valley and top. Values and peaks obtained were studied to derive comparison and propose reasons for success.
Result: Optical profilometry showed variation in implant surface roughness at amongst different location in the same implant system as well as within different implant systems. Roughest surface was observed for Indident and AB implant systems, the findings of which were consistent with those of SEM images for the respective systems. SEM analysis of Indident Implant showed amorphous pattern over the complete implant surface, whereas in case of AB and Bio Horizon, top region showed different morphology compared to the valley. Nobel Biocare sample showed difference in morphology compared to rest of the implant systems. EDX and XPS findings also correlated with those found via SEM analysis.

Keywords: Dental Implants; Scanning Electron Microscopy; Energy Dispersive X-Ray Spectroscopy; X-Ray Photoelectron Spectroscopy; Optical Imaging

1. INTRODUCTION

Implant based rehabilitation of lost tooth has gained tremendous success over the last decade. Newer designs are being constantly researched to improve clinical success compared to currently available systems. Dental implant surface is a critical aspect of designing, driving towards their success in form of osseointegration.[1] A variety of metals and metal alloys have been used as implant material; however, titanium (Ti) and its alloys (mainly titanium-aluminium-vanadium (Ti-6Al-4V)) remain to be the material of choice.[2] Surface topography potentially enhances osseointegration and can be achieved by using physical, chemical or mechanical methods.[3] Surface modification methods can also be classified as additive (layered application of new material on implant surface) or subtractive (removal of surface layer) processes, helping in achieving the desired results.[4,5] Depending on the type of treatment, considerable variation in the surface properties have been observed, providing variable clinical results.

Newer methods and chemical compositions have been tested to modify implant surface for improved properties. To name a few, these include use of calcium (Ca),[6] magnesium (Mg),[7,8] and nanoscale discrete crystalline deposits of calcium phosphate ($CaPO_4$)[9] to alter surface chemistry. Gurzawska *et al* found nanocoatings of organic molecules like carbon and graphene along with surface modifications with polysaccharides and glycosaminoglycans to be an effective way to stimulate bone regeneration on bone implant interface.[10]

Many studies have individually discussed the surface characteristics of different implant systems, however, few studies have compared the properties of currently available commercial systems. The present study aimed at comparing the surface characteristics and chemical composition of four, currently marketed dental implant systems namely; Indident™ dental implant system, AB© dental implant, BioHorizons© dental implant and Nobel Biocare™ dental implant.

2. Background of Dental Implant Systems Used

2.1 Indident™ Implant System (Sample A)

This Implant system was developed at the Institute of Nuclear medicine and Allied Sciences (INMAS), Defence Research and Development Organization (DRDO). It is a sand-blasted and acid etched implant which has found clinical use for single tooth replacement and implant supported denture. The implant is etched usinga patented method and subjected to sandblasting with aluminium oxide powder (Al_2O_3) and ultrasonic cleaning.[11]

2.2 AB© Implant System (Sample B)

According to the manufacturer, this is a Ti-6Al-4V implant manufactured by laser sintering. The implant undergoes special blasting with calcium phosphate ($CaPO_4$) to provide micro/nanoscale roughness, enhancing osseointegration.[12]

2.3 BioHorizon© Dental Implants (Sample C)

BioHorizon© dental implants are Laser-Loktapered internal implants, blasted with resorbable blast media. Laser-Lokmicro channels are a series of cell-sized circumferential channels that are precisely created using proprietary laser ablation technology which produces extremely consistent micro channels, optimally sized to attach and organize both, osteoblasts and fibroblasts.[13]

2.4 Nobel Biocare™ Dental Implants (Sample D)

These implants are manufactured from Ti Unite, a high performance implant surface material that enhances osseointegration even under the most challenging conditions. It is characterized by a moderately rough, thickened titanium oxide layer with high crystallinity and osteoconductive properties leading to faster bone formation.

3. MATERIALS AND METHODS

The following study was conducted in the Department of Dental Research and Implantology, INMAS, DRDO and Solid State Physics Laboratory (SSPL), DRDO. Surface characterization of four dental implant samples; A, B, C and D was done using optical profilometery, scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX) and X-ray photoelectron spectroscopy (XPS). Due to lack of availability of universal implant sizes among different commercial brands, implant sizes of approximately the same dimensions were selected for the purpose of compatibility (table 1). Universal precautions and sterility was maintained at all times to avoid surface contamination of implants.

Table 1: Detailed description of the dental implants used in the study

COMPANY	SURFACE	DESCRIPTION	LENGTH (mm)	WIDTH (mm)	LOT NUMBER
Indident	Sand blasted and acid etched	Cylindrical screw implant	10mm	4.2mm	IH3812SA
AB Implant System	Laser sintered surface, blasting with Calcium phosphate	Tapered implant with conical connections groovy neck	10mm	4.5mm	008180224186
BioHorizon Implant System	Laser-Lok	Tapered implant using Laser Ablation technology	9mm	4.0mm	1504641
Nobel Biocare Implant System	TiUnite	Replace Select Tapered	10mm	3.5mm	12102075

3.1 Optical Profilometry

Each dental implant was scanned at two locations; top and valley region using Taylor Hobson Precision Optical Profilometer (AMETEK Inc, Germany) to assess the surface roughness. The implants were placed on the microscope platform and results were recorded as fringes, which were used for analysis of roughness gradient. Surface roughness is expressed as arithmetical mean height (Sa). This device scans the surface topography of implant surface and quantitatively measures the surface roughness.

3.2 Scanning Electron Microscope (SEM) Analysis

Carl Zess Supra55 (Zeiss, Germany) SEM was used to observe implant surfaces at the same two positions as used in optical profilometry. An accelerated voltage of 20 kV and vacuum maintained at 1 x 10^{-5} torr was used. Implants were fixed to an Al sample holder with their long axis parallel to the holder using simple carbon conducting tape (Figure 1a). All four implants were studied at a range of 70X to 5000X magnification (Figure 1b).

3.3 Energy-dispersive X-ray Spectroscopy (EDX)

EDX was used to determine the elemental constitutes of dental implants. Implants were fixed on sample holder as done during SEM analysis, to allow a systematic scan. 7kV accelerating voltage was used to improve ratio for light elements. Two spectra from each implant were acquired which were then further analysed (Figure 1c).

3.4 X-ray photoelectron spectroscopy (XPS)

XPS was done to study the surface chemistry using Omicron XPS system (Scienta Omicron, Germany) using monochromatic A1 Kα X-ray source and a beam size of 400µm diameter. During spectra acquisition, electron take off angle was fixed at 35° and vacuum pressure maintained at below 2 x 10^{-10} torr. Survey XPS were acquired over 1000eV and resolution of 0.6eV(Figure 1d).

Figure 1: SEM setup; a: shows the placement of implants on aluminium implant holder, secured with carbon tapes, b: shows the sem analyses being done following proper sterile technique; Setup for c: EDX; d: XPS

4. RESULT

4.1 Optical Profilometry

Samples B and C showed higher roughness values in the valley region compared to top regions.

AB (Sample B) (Sa:0.745 µm) >BioHorizon (Sample C) (Sa:0.655 µm)

Surface roughness values for samples A and D could not be accurately determined due to unevenness of the implant surface thus leading to failure in obtaining conclusive values.

4.2 SEM analysis

Depending on surface treatment, different peaks were obtained for each implant sample. Sample A showed a very coarse, irregular and uneven surface (Figure 2a). Surface of sample B too showed irregular amorphous pattern with irregular micropores ranging from 1-2µm to even 10-15µm in diameters (Figure 2b). The top area of this implant showed microthread patterns which were evenly distributed (Figure 3b). Sample C showed grainy surface with minute crack like patterns present along the valley region of the implant, having a very regular serrated pattern, with fine threads present all over the top region (Figure 3c and 2c). Sample D demonstrated a relatively regular pattern with porous structures of different diameters ranging from 0.5µm to 10µm with a relatively smooth top region (Figure 3d and 2d).

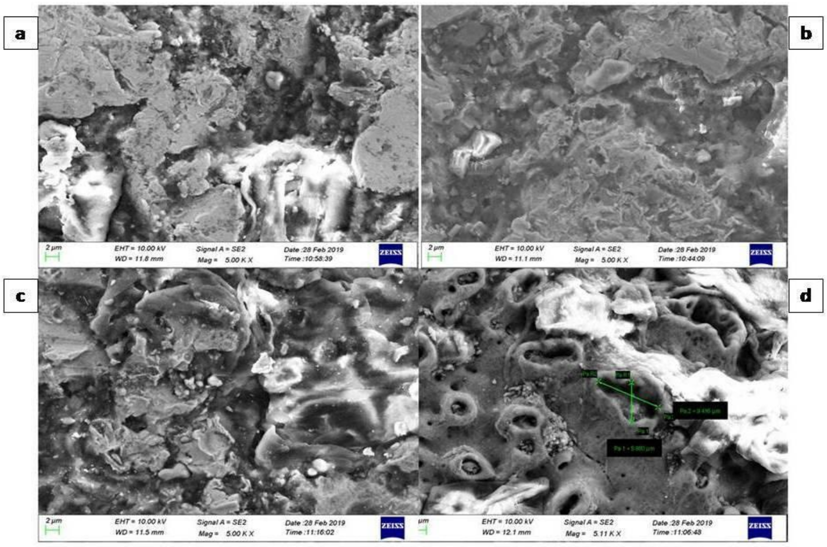

Figure 2: SEM pictures of top areas of implants: 70 X; a:Indident Implant, b: AB Implant, c: Bio Horizon implant, d: Nobel Biocare implant.

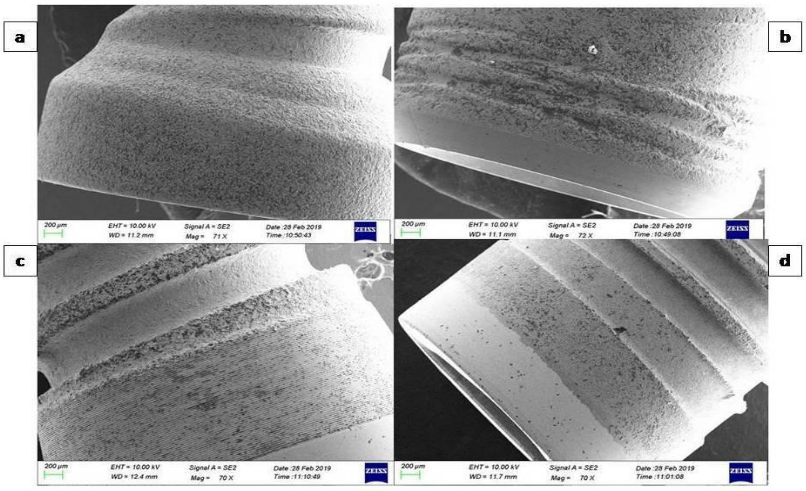

Figure 3: EDX analysis of Implant samples at top region; a:Indident Implant, b: AB Implant, c: Bio Horizon Implant, d: Nobel Biocare implant

4.3 EDX analysis

The analysis confirmed the presence of Ti in the elemental framework for all implants. Maximum amount of Ti was found in Sample A (97.43 wt %) followed by Sample D and C with the least content found in sample B. Additional presence of Al, silicon (Si) and V along with carbon (C) and oxygen (O) was seen in sample B (Figure 2b and 4b). This also suggested composition of Ti-Al-V alloy sandblasted by either silicon oxide (SiO_2) or silicon carbide (SiC) microspheres. Sample C too showed presence of Al, Si, C and O in the elemental spectrum along with Ti (Figure 2c and 4c). Sample D had peaks for calcium (Ca), phosphorous (P) and O in their elemental forms all over the implant surface except the neck region which only depicted presence of Ti (Figure 2d and 4d).

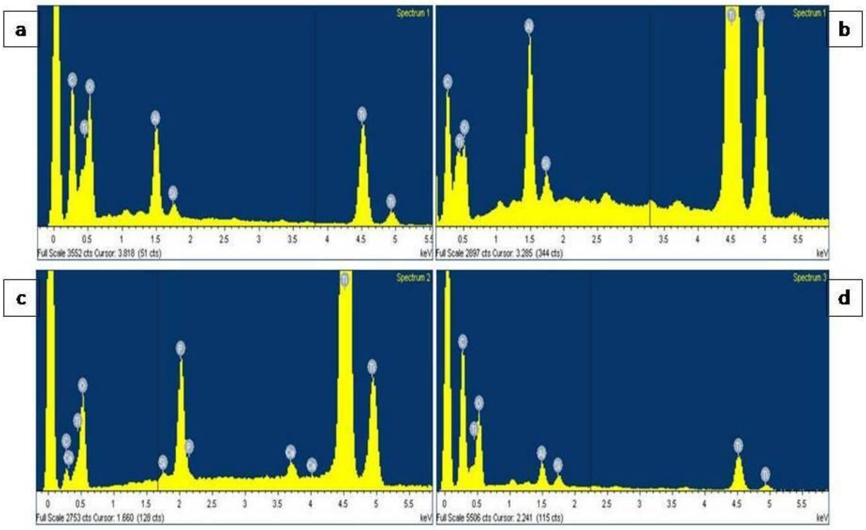

Figure 4: EDX analysis of implant samples at valley region; a:Indident Implant, b: AB Implant, c: Bio Horizon Implant, d: Nobel Biocare Implant

4.4 XPS analysis

The survey spectra showed major peaks at Ti 2p, O 1s and C 1s. Presence of Ti and Al were confirmed for sample A in the valley regions with traces of C and O. Sample B showed presence of Ti, Al, Si, V along with C and O in the valley region along with presence of iron (Fe), Chromium (Cr), Nickel (Ni), Manganese (Mn) elements in the top region of the implant. Sample C depicted Ti, Al, V over the top regions and a high probability of Ti-Al-Si alloy present in the valley region. XPS analysis of sample D was suggestive of material coating containing constituents of Ca, P, O and C. The binding energies of Ca and P were found to be shifted towards the higher side which may be an indicative towards coating of hydroxyapatite (HA) $Ca_{10}(PO_4)_6(OH)_2$ on implant surface.

5. DISCUSSION

Surface properties can be classified into mechanical, topographic and physiochemical properties.[14] In the surface properties of dental implants, topographic and physiochemical changes can be employed to improve osseointegration and primary implant stability.[15-17] A range of surface treatment techniques have been adopted, with each resulting in implant surface varying in morphology and chemistry. Strnad *et al* in their study concluded that SLA surfaces show stronger bone response and highest amount of bone-to-implant contact.[18] Supporting to this fact are the studies by Elias[19] and Ballo *et al,*[20] affirming that these procedure increase the surface roughness over the implant, promoting rapid osseointegration. In this study, four, clinically successful, commercially available dental implant were subjected to in-vitro analysis to compare their surface characteristics.

The surface roughness is an essential component of surface topography, enhancing osseointegration[17] and was compared through 3D evaluation. It was expressed as Sa which describes 3D roughness measurement and is more reliable and advanced method than 2D measurement (Ra) of the roughness quotient. Numerous studies have shown surface roughness of titanium implants to affect the rate of osseointegration and biomechanical fixation. [21-23] Roughness values between 1 to1.5µm have shown to provide optimal surface for proper bone integration. In our study we saw different surface roughness at different locations in the same implant. Sample B and C showed increased surface roughness over top areas as compared to the valley region. This can be due to the presence of microthread pattern present in both these implant systems. No significant difference in surface values at the two sites was noted for sample D.

SEM study of these implant systems revealed the surface morphology and effect of manufacturing process on implant surface. Sample A has been developed as a commercially pure Ti derived cylindrical implant which is sand blasted and acid etched. Likewise, sample B has also been stated to have undergone blasting with $CaPO_4$. We believe, this maybe the reason that both these implants showed similarity in their SEM derived topographical findings. Irregular grainy particles of varied dimensions were seen in both the samples; however, sample B showed particles of more uneven shapes and sizes with prominent cracks, showing appearance of molten matter in between. These particles were present in a layered pattern resulting in creation of a more rough surfaced alloy with very uneven surface. Microthread present on the surface of sample B implant was yet another distinguishing finding. Sample C also showed the presence of fine, regular groove like pattern around the top region with minute crack like regions in the valley. These findings were in accordance with those of Brunette *et al* and Massaro *et al* on machined turned or blasted implants.[24,25] Findings for sample D showed presence of minute pores over the entire implant surface.

EDX and XPS analysis for the purpose of surface chemistry showed Ti, Al, O and C as major elements in the elemental framework for all systems studied. These findings were consistent with previous findings by Massaro *et al,*[25] Olefjord *et al,*[26] and Kang *et al.*[27] AB implant sample showed the presence of Ti, along with Al and V, suggestive of Ti-Al-V alloy. XPS graphs also showed the presence of Fe, Mn, Cr and Ni peaks. Similarly, BioHorizon implant also had traces of Al and V over the implant. Apart from these, XPS and EDX analysis of Nobel Biocare implant suggest a coating of Ca and P. Binding energies of Ca and P are seen to be shifting to higher side suggestive of presence of hydroxyapatite like coating over the implant surface.

6. CONCLUSION

This study displayed the distinct surface characteristics of four implant systems which are actively used in clinical practice. Slight variations in surface roughness and composition were seen for each system with samples A and B showing the roughest surface among all. Differences in modeling were also seen with presence of microthreads in sample C. The current study proposes for conduction of similar analysis for other implant systems and comparison of the findings with clinical results to be able to find a combination that can provide superior holistic clinical success.

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Conflict of Interest

This research is free of any conflict of interest.

Data availability

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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