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Evaluation on Topography, Surface Chemical Composition, and Hydrophilicity of Fifteen Commercially Available Implant Systems

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Abstract

The aim of this study was to investigate implant surface topography, chemical composition, and hydrophilicity of commercially available implant systems. A total of fifteen implant systems, including Cowellmedi INNO, Straumann Roxolid, Neodent CM DRIVE, ADIN Touareg-S Spiral, Alpha Bio Tec SPI, MIS Lance, S.I.N Unitite, Ankylos C/X Implant, Xive S Plus, AstraTech Implant system EV-OsseoSpeed, BioHorizons Tamper Evident, Zimmer Biomet OsseoTite, Nobelbiocare NobelActive, Nobelbiocare NobelReplace, and Bicon Short, were investigated through scanning electron microscopy (SEM), energy disperse X-ray (EDAX), X-ray photoelectron spectroscopy (XPS), ion chromatography (IC), inductively-coupled plasma-atom (ICP), and hydrophilicity test. Cowellmedi INNO was the only implant system that presented hydrophilicity without nano-roughness of surface among the investigated implant systems.Thus, hydrophilicity may be determined by chemical composition rather than surface roughness.

Introduction

Dental implant has become a valid treatment option for rehabilitation of partial or full edentulism, and its success is largely associated with osseointegration between the implant surface and bone. The concept of osseointegration was first introduced by Branemark et al. in 1969 [2]. Since then, a number of researches have focused on implant surface modification in order to encourage the process of osseointegration at the implant-bone interface.

It is well-known that an increased implant surface topography, roughness in particular, reinforces mechanical interlock between implant and bone and enhances cellular activities necessary for bone healing because an increase in roughness derives an increase in surface area, inducing more sites for biomechanical interactions [3-5,12,16]. According to the three-dimensional characteristics, implant topography can be categorized into macro-, micro-, and nano-roughness. Since the first report on the increased adhesion of osteoblasts by nanomaterials was revealed in 1999 [16], numerous investigations have highlighted on nanomaterials: they not only display biological properties of enhanced protein adsorption, cellular differentiation, and extracellular matrix secretion but also demonstrate higher surface energy, which essentially increases hydrophilicity [1,15,16].

Implant surface hydrophilicity has been considered important in the initial stage of osseointegration. Hydrophilicity may be beneficial during the initial stages of osseointegration as implant surface initially interacts with biofluids once placed inside the body. The previous In-vitro studies have shown that higher levels of differentiation markers including alkaline phosphatase and osteocalcin are observed on hydrophilic surfaces [10,23]. Moreover, the in-vivo studies have demonstrated accelerated healing period, greater bone-to-implant contact, and removal torque from implants with hydrophilicity, which is largely associated to chemical composition, topography, and presence of hydrocarbon contamination [14,19,20]

Several studies have revealed the effect of various surface characteristics and modifications on osseointegration. However, a few studies have investigated the surface characteristics of commercially available implants. Hence, the present study was to examine the surface properties including its topography, chemical composition, and hydrophilicity of fifteen different commercially available products.

Materials and methods

Implants

15 different implants and 11 manufacturers were under examination as described in Table 1.

Implant Manufacturer	Implant System	Surface Name	Surface Treatment
Cowellmedi Korea (Busan)	INNO	INNO SLA-SH	Sandblasting and acid-etching Calcium phosphate ion coating
Straumann Switzerland (Basel)	Roxolid	SLActive	Modified Sandblasting and acid-etching
	Neodent Brazil (Curitiba) CM DRIVE	Acqua	Sandblasting and acid-etching
ADIN Israel (Afula)	Touareg-S	AB/AE	Sandblasting and acid-etching
Alpha Bio Tec Israel (Petah Tikva)	SPI	N/A	Sandblasting and acid-etching
MIS Israel (Nahariya)	LANCE	N/A	Sandblasting and acid-etching
S.I.N Brazil (San Paulo)	Unitite	HA	Sandblasting and acid-etching Nano-active coating
Dentsply Sirona USA (New York)	Ankylos Germany (Mannheim) C/X Implant	FRIADENT®plus	Sandblasting and acid-etching
	Xive Germanry (Mannheim) Xive S Plus	FRIADENT®plus	Sandblasting and acid-etching
	AstraTech Sweden (Stockholm) Implant system EV	OsseoSpeed	Resorbable Blast Media Top sanding with TiO2
BioHorizons USA (Birmingham)	Tamper Evident	Laser-Lock	Resorbable Blast Media Laser-Lock®
Zimmer Biomet USA (Palm Beach Gardens)	OsseoTite	Surface Name	Dual acid-etching
Nobelbiocare Switzerland (Zurich)	NobelActive	TiUnite	Anodic Spark Deposition
	NobelReplace	TiUnite	Anodic Spark Deposition
Bicon USA (Boston)	Short®	N/A	Titanium plasma spray Hydroxyapatite layers

Table 1. Implant manufacturer, system, surface name, and surface treatment of the implant samples

Test devices

Scanning Electron Microscope (SEM)/ Energy Disperse X-ray (EDAX) : the surface morphology of implant was analyzed with Quanta 200 FEG (FEI, Oregon, USA) scanning electron microscopy at accelerating voltage of 15 kV and working distance (WD) of 11.4 mm and 12 mm for magnifications of 5000x and 260000x in high vacuum. The microscopy was equipped with Energy Disperse X-ray detector, enabling chemical analysis of implant surface.

X-ray photoelectron spectroscope (XPS): quantitative and qualitative chemical analysis of implant surface was carried out by AXIS Ultra DLD (Kratos Analytical, Manchester, UK) x-ray photoelectron spectroscopy.

Ion Chromatography (IC): separation and quantitative analysis of anions, such as halogen, from implant surface was performed with ICS-6000 HPIC system (Dionex, Sunnyvale, USA).

Inductively-coupled Plasma-atomic emission Spectrometry (ICP): the elemental analysis was done on ACTIVA-M ICP-AES spectrometer (Horiba, Tokyo, Japan).

Hydrophilicity test: a drop of deionized water was placed in contact with implant, and moistening of implant surface was observed.

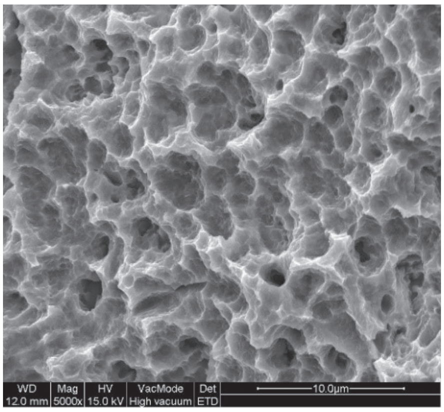
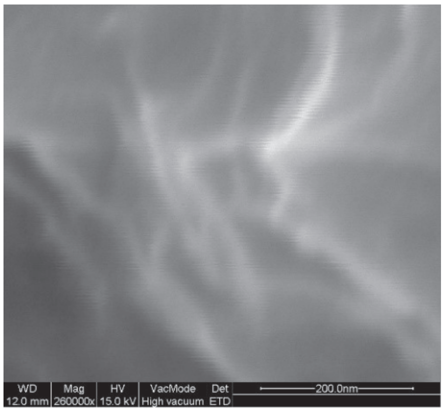
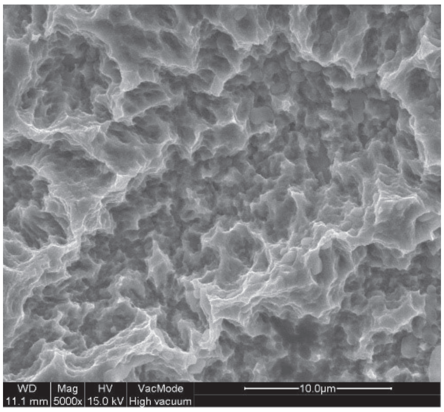
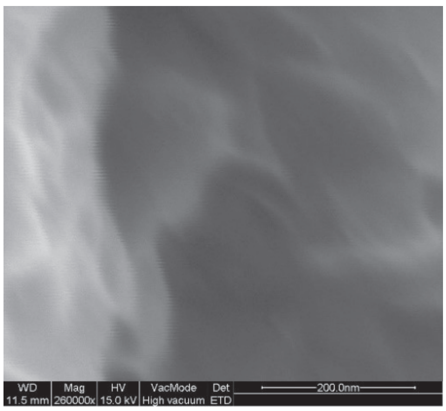
Results

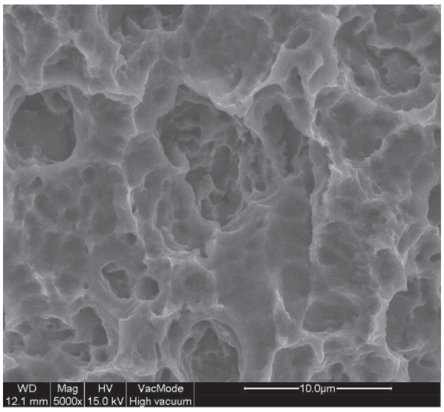
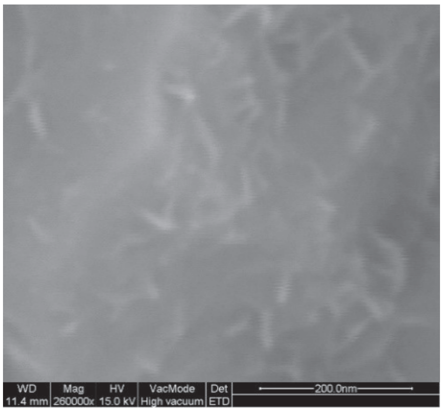
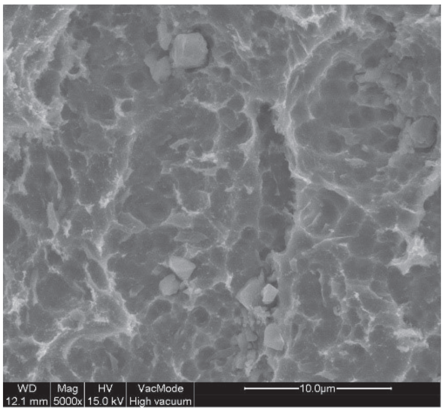
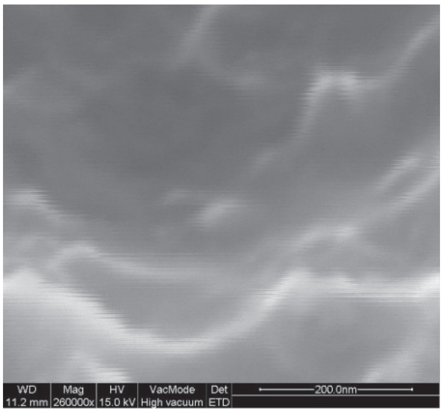
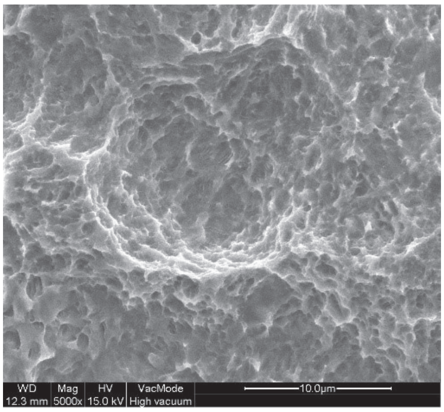
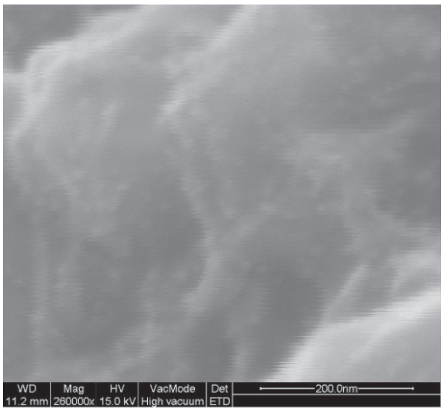
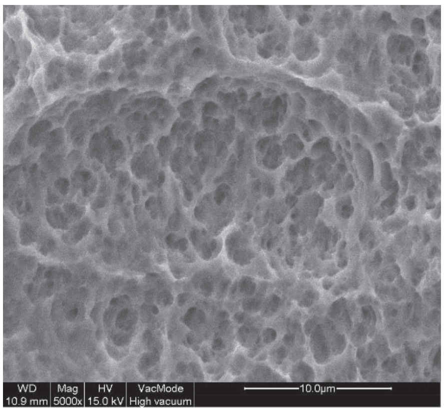
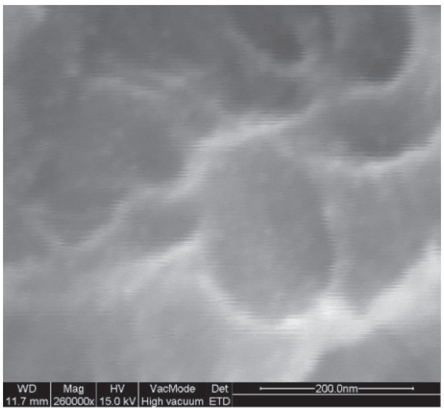
Hydrophilicity

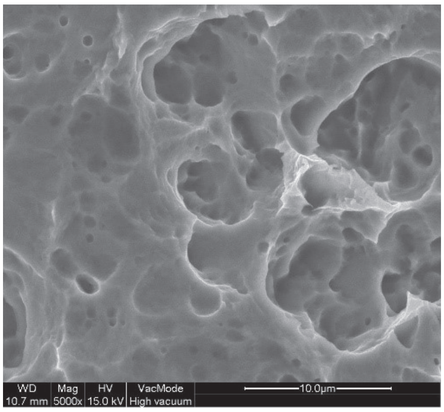
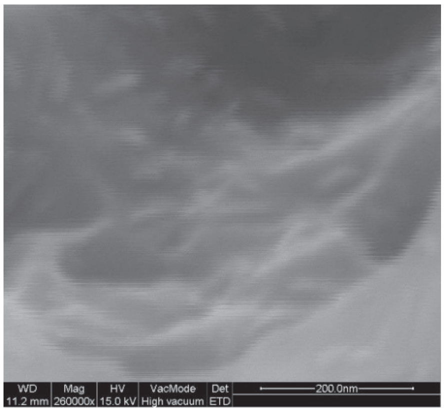
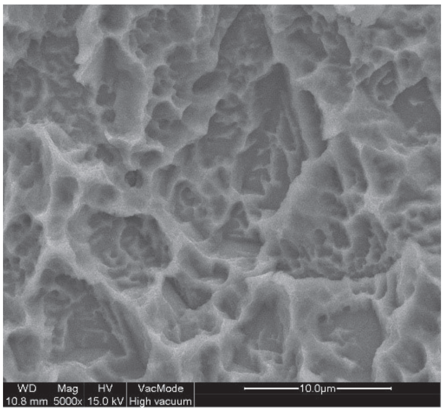
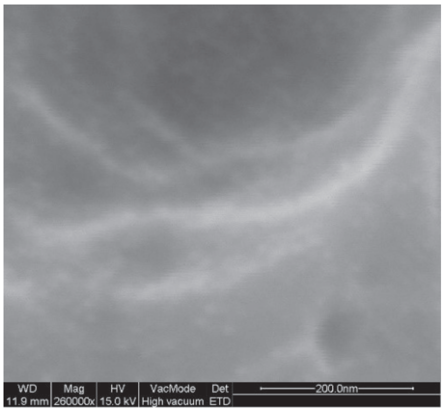
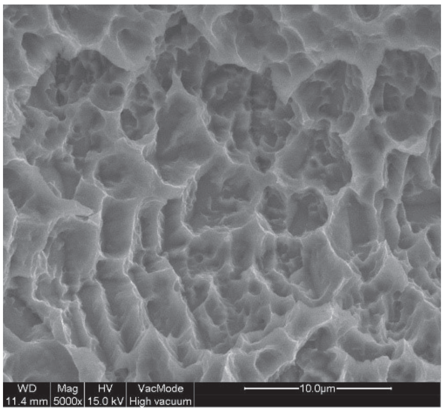
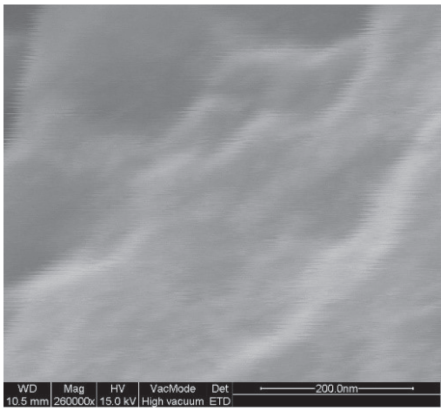
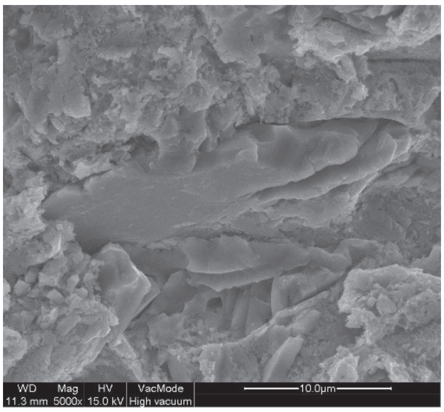
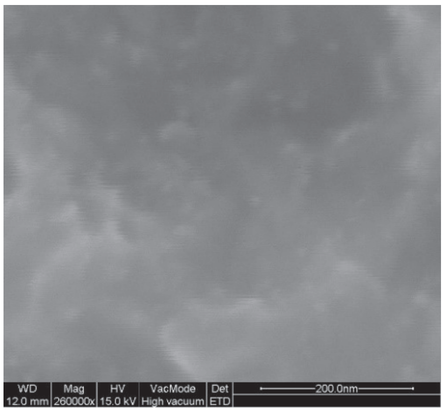
Among the fifteen different implant systems, only Cowellmedi INNO implant showed immediate hydrophilicity when the implant was in contact with DI water.

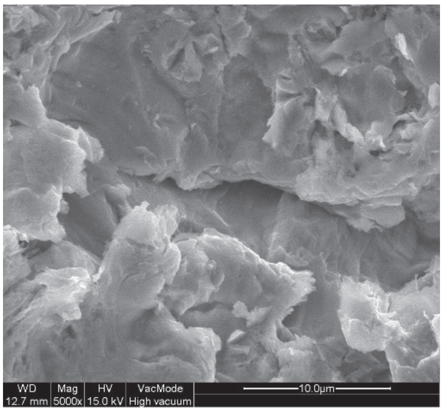
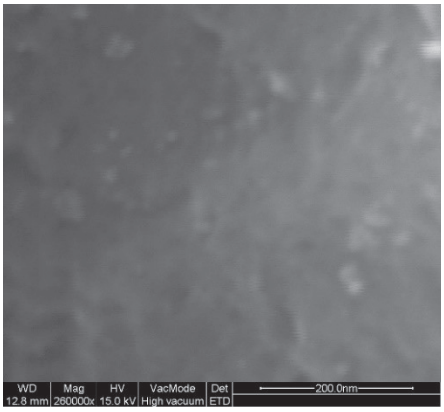
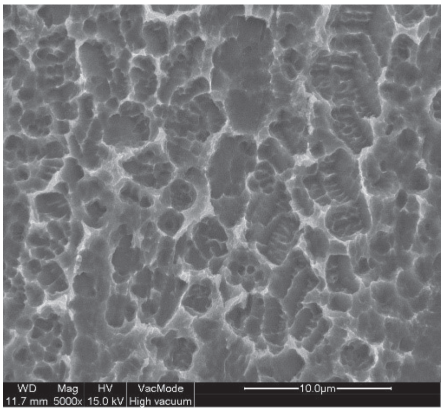
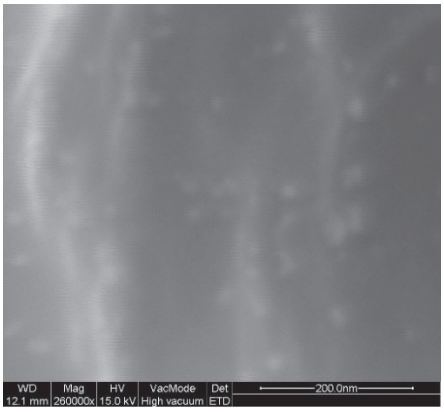
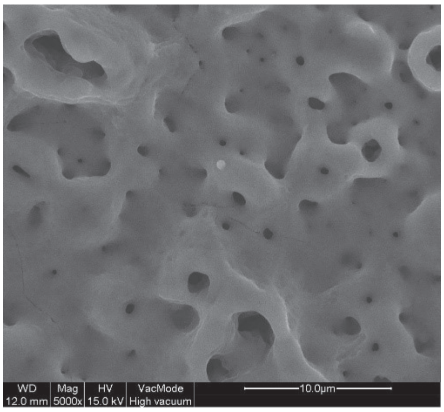
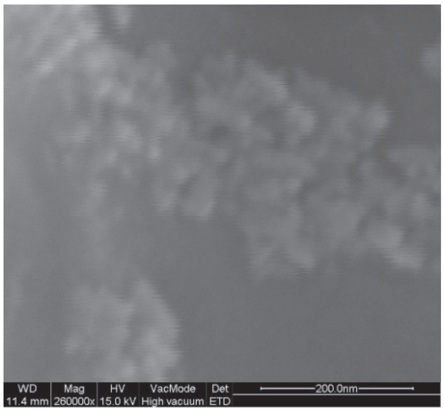
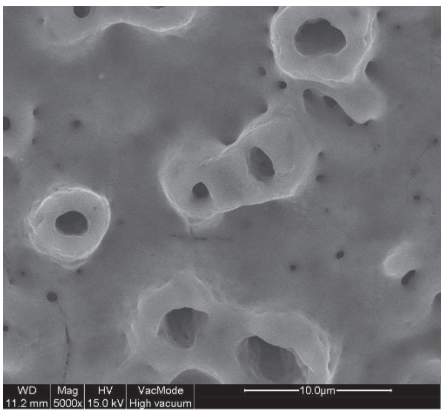
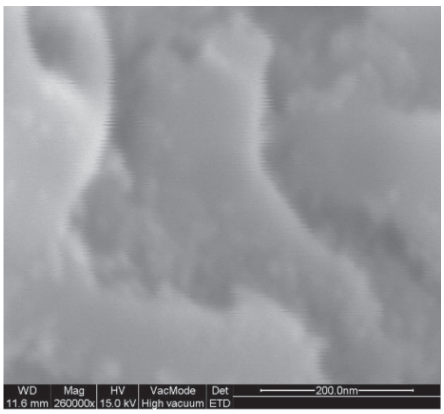
Scanning Electron Microscope (SEM)

The difference in implant surface topography was analyzed at micro and nano scales with SEM images shown in Table 2. At microscale, all the implants showed relatively rough surfaces with different patterns: sandblasted with large grit and acid etched (SLA) implants (Cowellmedi INNO, Straumann Roxolid, Neodent CM DRIVE, ADIN Touareg-S Spiral, Alpha Bio Tec SPI, MIS Lance, S.I.N Unitite, Ankylos C/X implant, and Xive S Plus) showed spongy-like pattern with different sizes of pores, resorbable blast media (RBM) implants (AstraTech Implant system EV-OsseoSpeed, and BioHorizons Tamper Evident) demonstrated irregularly rough surfaces, dual acid-etching implant (Zimmer Biomet OsseoTite) had bi-layered porosity, anodic spark deposition (ASD) implants (Nobelbiocare NobelActive and NobelReplace) manifested volcano-like indentations, and titanium plasma spray implant (Bicon Short) showed relatively bulky appearance. In addition, all the implants, except Cowell INNO, were commonly covered with millet-like prominences, projecting nano-roughness.

Implant	5000x	260000x
Cowellmedi INNO		
Straumann Roxolid		

Neodent CM DRIVE		
ADIN Touareg-S Spiral		
Alpha Bio Tec SPI		
MIS Lance		

S.I.N Unitite		
Ankylos C/X Implant		
Xive S Plus		
AstraTech Implant system EV-OsseoSpeed		

BioHorizons Tamper Evident		
Zimmer Biomet OsseoTite		
Nobelbiocare NobelActive		
Nobelbiocare NobelReplace		

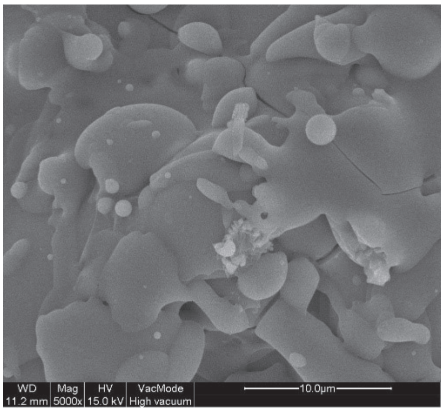
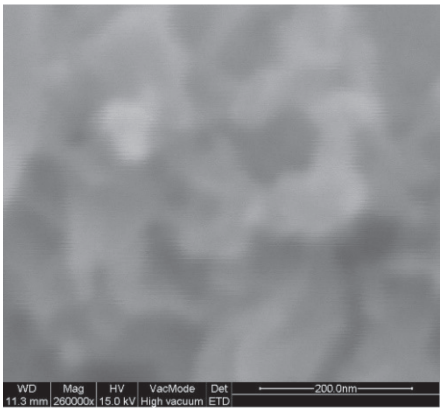
Bicon Short		

Table 2. SEM images of implant surface.

Chemical Composition of Implant Surface

Element	Cowellmedi INNO At(%)	Straumann Roxolid At(%)	Neodent CM DRIVE At(%)	ADIN Touareg-S Spiral At(%)	Alpha Bio Tec SPI At(%)	MIS Lance At(%)	S.I.N Unitite At(%)	Ankylos C/X Implant At(%)	Xive S Plus At(%)	AstraTech Implant system EV-OsseoSpeed At(%)	BioHorizons Tamper Evident At(%)	Zimmer Biomet OsseoTite At(%)	Nobelbiocare NobelActive At(%)	Nobelbiocare NobelReplace At(%)	Bicon Short At(%)
B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C	15.56	20.35	5.82	9.74	8.51	ND	5.6	31.77	6.81	3.89	12.45	11.20	3.24	1.58	31.31
N	ND	9	24.97	18.64	30.19	25.61	26.9	8.14	31.56	18.79	40.67	16.76	11.79	9.15	ND
O	38.15	12.3	4.11	29.33	18.88	26.30	25.74	12.73	13.61	43.31	ND	17.45	46.27	42.57	35.42
F	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mg	ND	ND	ND	0.58	ND	ND	ND	ND	ND	ND	ND	ND	0.45	ND	0.42
Na	ND	9	13.12	0.98	ND	ND	ND	1.18	ND	ND	ND	1.50	ND	ND	ND
As	ND	ND	ND	10.16	ND	ND	ND	0.72	ND	ND	ND	ND	ND	ND	ND
Al	ND	15.64	ND	ND	11.39	15.93	ND	ND	ND	ND	7.41	ND	ND	ND	1.78
S	ND	ND	ND	0.34	ND	ND	ND	0.17	ND	ND	ND	ND	ND	ND	ND
Si	ND	0.23	ND	ND	0.56	ND	ND	ND	ND	0.36	1.07	ND	ND	ND	ND
P	2.7	3.1	ND	ND	ND	ND	0.93	ND	ND	ND	ND	ND	6.67	ND	7.61
Tc	ND	ND	ND	ND	ND	ND	ND	0.58	ND	ND	ND	ND	ND	6.07	ND
Cl	ND	5.77	8.3	ND	ND	ND	0.27	ND	ND	ND	ND	ND	ND	ND	ND
Ca	3.46	0.59	ND	ND	ND	ND	1.18	0.72	ND	ND	ND	2.5	0.19	ND	7.61
Ti	41.51	24.03	43.69	30.22	30.47	32.16	40.91	43.98	48.02	33.78	43.26	52.09	31.38	40.63	12.42
Fe	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 3. Result of Energy Disperse X-ray (EDAX) in atomic percentage.

Element	Cowellmedi INNO At(%)	Straumann Roxolid At(%)	Neodent CM DRIVE At(%)	ADIN Touareg-S Spiral At(%)	Alpha Bio Tec SPI At(%)	MIS Lance At(%)	S.I.N Unitite At(%)	Ankylos C/X Implant At(%)	Xive S Plus At(%)	AstraTech Implant system EV-OsseoSpeed At(%)	BioHorizons Tamper Evident At(%)	Zimmer Biomet OsseoTite At(%)	Nobelbiocare NobelActive At(%)	Nobelbiocare NobelReplace At(%)	Bicon Short At(%)
C1s	11	28.76	26.52	29.62	34.1	27.65	18.65	27.2	25.08	29.94	23.5	28.97	25.08	20.2	23.67
Ca2p	4.55	0.98	ND	ND	ND	ND	12.46	ND	ND	ND	ND	ND	ND	ND	12.85
Cl2p	ND	5.82	22.08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N1s	1.53	ND	ND	ND	2.92	1.32	ND	2.09	1.97	ND	2.55	2.46	2.24	2.05	1.01
F1s	ND	ND	ND	1.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Na1s	2.9	7.19	25.41	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.76
O1s	62.71	41.95	17.64	52.59	49.83	54.82	53.81	53.01	54.13	51.46	56.68	52.98	53.14	56.42	47.42
P2p	10.64	ND	ND	ND	ND	ND	8.98	ND	ND	ND	2.08	ND	7.36	8.29	10.28
Si2p	ND	ND	ND	4.07	ND	ND	ND	ND	ND	ND	2.07	ND	ND	ND	ND
S2p	ND	ND	ND	ND	ND	ND	0.86	ND	ND	ND	ND	ND	ND	ND	ND
Ti2p	12.93	13.73	7.09	12.16	13.14	16.2	5.24	17.71	18.82	18.6	13.12	15.6	12.18	13.04	ND
Zr3d	ND	1.57	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn2p3	ND	ND	1.25	0.57	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 4. Result of X-ray Photoelectron Spectroscope (XPS) at implant apex in atomic percentage (At%).

Element	Cowellmedi INNO At(%)	Straumann Roxolid At(%)	Neodent CM DRIVE At(%)	ADIN Touareg-S Spiral At(%)	Alpha Bio Tec SPI At(%)	MIS Lance At(%)	S.I.N Unitite At(%)	Ankylos C/X Implant At(%)	Xive S Plus At(%)	AstraTech Implant system EV-OsseoSpeed At(%)	BioHorizons Tamper Evident At(%)	Zimmer Biomet OsseoTite At(%)	Nobelbiocare NobelActive At(%)	Nobelbiocare NobelReplace At(%)	Bicon Short At(%)
C1s	14.99	27.58	24.53	31.84	40.62	36.94	17.65	27.20	25.08	29.94	23.65	31.64	25.31	21.93	25.18
Ca2p	2.21	ND	ND	ND	ND	ND	14.22	ND	ND	ND	ND	ND	ND	ND	13.26
Cl2p	ND	20.31	28.19	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N1s	0.94	ND	ND	ND	2.37	0.93	ND	2.09	1.97	ND	2.77	1.82	1.30	2.20	ND
F1s	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Na1s	2.56	26.85	32.29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.88
O1s	62.10	17.22	11.27	59.87	45.02	48.09	53.99	53.01	54.13	51.46	54.96	50.03	53.43	55.15	47.83
P2p	5.43	ND	ND	ND	ND	ND	11.33	ND	ND	ND	3.40	ND	5.94	9.12	11.85
Si2p	ND	ND	ND	4.32	ND	ND	ND	ND	ND	ND	3.58	ND	ND	ND	ND
S2p	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ti2p	19.69	6.88	3.34	9.97	11.98	14.04	2.81	17.71	18.82	18.60	11.64	16.51	14.03	11.62	ND
Zr3d	ND	1.16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn2p3	ND	ND	0.38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 5. Result of X-ray Photoelectron Spectroscope (XPS) at implant neck in atomic percentage (At%).

Element	Cowellmedi INNO At(%)	Straumann Roxolid At(%)	Neodent CM DRIVE At(%)	ADIN Touareg-S Spiral At(%)	Alpha Bio Tec SPI At(%)	MIS Lance At(%)	S.I.N Unitite At(%)	Ankylos C/X Implant At(%)	Xive S Plus At(%)	AstraTech Implant system EV-OsseoSpeed At(%)	BioHorizons Tamper Evident At(%)	Zimmer Biomet OsseoTite At(%)	Nobelbiocare NobelActive At(%)	Nobelbiocare NobelReplace At(%)	Bicon Short At(%)
F^{5}-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cl^{-}	ND	5.549	8.48	0.025	0.015	ND	0.002	ND	ND	ND	ND	ND	ND	0.007	0.007
NO_2^{-}	ND	0.021	ND	0.038	0.016	ND	0.024	ND	ND	0.018	ND	0.031	ND	ND	0.069
SO_4^{2-}	ND	0.007	0.005	0.028	0.084	ND	0.014	ND	ND	ND	ND	ND	0.446	0.456	0.031
Br^{-}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NO_3^{-}	ND	0.027	0.008	0.049	0.022	0.005	0.032	0.007	0.004	0.026	0.005	0.041	0.001	0.009	0.078
PO_4^{3-}	0.61	ND	ND	ND	ND	ND	1.028	ND	ND	ND	0.026	ND	0.393	0.392	ND

Table 6. Result of Ion Chromatography (IC)

Element	Cowellmedi INNO At(%)	Straumann Roxolid At(%)	Neodent CM DRIVE At(%)	ADIN Touareg-S Spiral At(%)	Alpha Bio Tec SPI At(%)	MIS Lance At(%)	S.I.N Unitite At(%)	Ankylos C/X Implant At(%)	Xive S Plus At(%)	AstraTech Implant system EV-OsseoSpeed At(%)	BioHorizons Tamper Evident At(%)	Zimmer Biomet OsseoTite At(%)	Nobelbiocare NobelActive At(%)	Nobelbiocare NobelReplace At(%)	Bicon Short At(%)
Ca	0.09	0.07	0.01	0.03	0.04	0.02	ND	0.01	ND	ND	0.01	0.02	ND	ND	5.26
Na	0.01	3.45	5.12	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.04
K	ND	0.01	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	0.09	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Mg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.04
Al	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.17
Zn	ND	ND	ND	0.07	0.46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
P	0.17	ND	ND	ND	ND	ND	0.38	ND	ND	ND	ND	ND	0.14	0.14	1.53
Si	ND	ND	0.01	0.26	0.01	ND	0.01	ND	0.03	0.01	0.03	ND	ND	0.01	0.12
As,Pb,Cd,Hg, Sn,Cu,Cr,Fe	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 7. Result of Inductively-coupled Plasma-atom (ICP).

Cowellmedi INNO implant was composed 15.56 at%(atomic percent) of Carbon (C), 38.15 at% of Oxygen (O), 2.70 at% of Phosphate (P), 3.46 at% of Calcium (Ca), and 41.51 at% of Titanium (Ti) according to energy disperse X-ray (EDAX) as shown in Table 3. Through X-ray photoelectron spectroscope (XPS), 11.00% of C1s, 4.55% of Ca2p, 1.53% N1s, 2.90% of Na1s, 62.71% of O1s, 10.64% of P2p, and 12.93% of Ti2p were confirmed at the implant apex while 14.99% of C1s, 2.21% of Ca2p, 0.94% of N1s, 2.56% of Na1s, 62.10% of O1s, 5.43% of P2p, and 19.69% of Ti2p in atomic percentage were displayed at the implant neck (Table 4,5). The implant presented 0.61 mg/L of PO_4^{3-} from ion chromatography (IC) and 0.09 mg/L of Ca, 0.01 mg/L of Sodium (Na), and 0.17 mg/L of P from inductively-coupled plasma-atom(ICP) as described in Table 6 and 7.

Straumann Roxolid showed 20.35% of C, 9.00% of Nitrogen (N), 12.30% of O, 9.00% of Na, 15.64% of Aluminum (Al), 0.23% of Silicon (Si), 3.10% of P, 5.77% of Chloride (Cl), 0.59% of Ca and 24.03% of Ti in atomic percentage on EDAX. Its apex had 28.76% of C1s, 0.98% of Ca2p, 5.82% of Cl2p, 7.19% of Na1s, 41.95% of O1s, 13.73%of Ti2p, and 1.57% of Zr3d in atomic percentage, and the neck indicated 27.58% of C1s, 20.31% of Cl2p, 26.85% of Na1s, 17.22% of O1s, 6.88% of Ti2p, and 1.16% of Zr3d in atomic percentage. IC presented 5.549 mg/L of Cl^-, 0.021 mg/L of NO_2^-, 0.007 mgL of SO_4^{2-}, and 0.027 mg/L of NO_3^-. According to ICP, the implant demonstrated of 0.07 mg/L of Ca, 3.45 mg/L of Na, and 0.01mg/L of Potassium (K).

Neodent CM DRIVE indicated 5.82 at% of C, 24.97 at% of N, 4.11 at% of O, 13.12 at% of Na, 8.30 at% of Cl, and 43.69 at% of Ti on EDAX while 26.52 at% of C1s, 22.08 at% of Cl2p, 25.41 at% of Na1s, 17.64 at% of O1s, 7.09 at% of Ti2p, and 1.25 at% of Zn2p3 at implant apex and 24.53 at% of C1s, 28.19 at% of Cl2p, 32.29 at% of Na2s, 11.27 at% of O1s, 3.34 at% of Ti2p, and 0.38 at% of Zn2p3 at implant neck were found on XPS. 8.48 mg/L of Cl^-, 0.005 mg/L of SO_4^{2-}, and 0.008 mg/L of NO_3^- were shown on IC while 0.01 mg/L of Ca, 5.12 mg/L of Na, and 0.01 mg/L of Si were found on ICP.

ADIN Touareg-S Spiral had 9.74 at% of C, 18.64 at% of N, 29.33 at% of O, 0.58 at% of Mg, 0.98 at% of Na, 10.16 at% of As, 0.34 at% of S and 30.22 at% of Ti on EDAX, 29.62 at% of C1s, 1.01 at% of F1s, 52.59 at% of O1s, 4.07 at% of Si2p, 12.16 at% of Ti2p, and 0.57 at% of Zn2p3 at its apex on XPS, and 31.84 at% of C1s, 59.87 at% of O1s, 4.32 at% of Si2p, and 9.97 at% of Ti2p at its neck on XPS. IC showed 0.025 mg/L of Cl^-, 0.038 mg/L of NO_2^-, 0.028 mg/L of SO_4^{2-}, and 0.049 mg/L of NO_3^-, and ICP demonstrated 0.03 mg/L of Ca, 0.01 mg/L of Na, 0.01 mg/L of K, 0.09 mg/L of Nickel(Ni), 0.07 mg/L of Zinc(Zn), and 0.26 mg/L of Si.

Alpha Bio Tec SPI exhibited 8.51 at% of C, 30.19 at% of N, 18.88 at% of O, 11.39 at% of Al, 0.56 at% of Si, and 30.47 at% of Ti on EDAX. At its apex, 34.10 at% of C1s, 2.92 at% of N1s, 49.83 at% of O1s, and 13.14 at% of Ti2p were revealed while 40.62 at% of C1s, 2.37 at% of N1s, 45.02 at% of O1s, and 11.98 at% of Ti2p were at its neck. The implant showed 0.015mg/L of Cl^-, 0.016 mg/L of NO_2^-, 0.084 mg/L SO_4^{2-}, and 0.022 mg/L of NO_3^- on IC while 0.04 mg/L of Ca, 0.46 mg/L of Zn, and 0.01 mg/L of Si on ICP.

MIS Lance manifested 25.61 at% of N, 26.30 at% of O, 15.93 at% of Al, and 32.16 at% of Ti on EDAX. 27.65 at% of C1s, 1.32 at% of N1s, 54.82 at% of O1s, and 16.20 at% of Ti2p were confirmed at its apex on XPS while it showed 36.94 at% of C1s, 0.93 at% of N1s, 48.09 at% of O1s, and 14.04 at% of Ti2p at the neck. IC presented 0.005 mg/L of NO_3^- while ICP showed 0.02 mg/L of Ca.

S.I.N Unitite manifested 5.60 at% of C, 26.90 at% of N, 25.74 at% of O, 0.93 at% of of P, 0.27 at% of Cl, 1.18 at% of Ca, and 40.91 at% of Ti on EDAX. XPS showed 18.65 at% of C1s, 12.46 at% of Ca2p, 53.81 at% of O1s, 8.98 at% of P2p, 0.86 at% of S2p, and 5.24 at% of Ti2p at its apex while 17.65 at% of C1s, 14.22 at% of Ca2p, 53.99 at% of O1s, 11.33 at% of P2p, and 2.81 at% of Ti2p at its neck. IC revealed 0.002 mg/L of Cl^-, 0.024 mg/L of NO_2^-, 0.014 mg/L of SO_4^{2-}, 0.032 mg/L of NO_3^- and 1.028 mg/L of PO_4^{3-}. ICP demonstrated 0.38 mg/L of P and 0.01 mg/L of Si.

Ankylos C/X Implant presented 31.77 at% of C, 8.14 at% of of N, 12.73 at% of O, 1.18 at% of Na, 0.72 at% of Arsenic (As), 0.17 at% of Sulfur (S), 0.58 at% of Technetium (Tc), 0.72 at% of Ca, and 43.98 at% of Ti on EDAX. XPS showed 27.20 at% of C1s, 2.09 at% of N1s, 53.01 at% of O1s, and 17.71 at% of Ti2p at the apex while 27.20 at% of C1s, 2.09 at% of N1s, 53.01 at% of O1s, and 17.71 at% of Ti2p at the neck. IC exhibited 0.007 mg/L of NO_3^-, and ICP demonstrated 0.01 mg/L of Ca.

Xive S Plus had 6.81 at% of C, 31.56 at% of N, 13.61 at% of O, and 48,02 at% of Ti on EDAX, 25.08 at% of C1s, 1.97 at% of N1s, 54.13 at% of O1s, and 18.82 at% of Ti2p at its apex on XPS, and 25.08 at% of C1s, 1.97 at% of N1s, 54.13 at% of O1s, and 18.82 at% of Ti2p at its neck on XPS. In addition, 0.004 mg/L of NO_3^- was found on IC while 0.03 mg/L of Si was shown on ICP.

AstraTech Implant system EV-OsseoSpeed demonstrated 3.89 at% of C, 18.79 at% of N, 43.31 at% of O, 0.36 at% of Si, and 33.78 at% of Ti on EDAX. XPS confirmed 29.94 at% of C1s, 51.46 at% of O1s, and 18.60 at% of Ti2p at apex and 29.94 at% of C1s, 51.46 at% of O1s, and 18.60 at% of Ti2p at neck. IC presented 0.018 mg/L of NO_2^-- and 0.026 mg/L of NO_3^- . ICP displayed 0.01 mg/L of Si.

BioHorizons Tamper Evident showed 12.45 at% of C, 40.67 at% of N, 7.41 at% of Al, 1.07 at% of Si, and 43.26 at% of Ti on EDAX. XPS revealed 23.50 at% of C1s, 2.55 at% of N1s, 56.68 at% of O1s, 2.08 at% of P2p, 2.07 at% of Si2p, and 13.12 at% of Ti2p at the apex and 23.65 at% of C1s, 2.77 at% of N1s, 54.96 at% of O1s, 3.40 at% of P2p, 3.58 at% of Si2p, and 11.64 at% of Ti2p at the neck. IC demonstrated 0.005 mg/L of NO_3^- and 0.026 mg/L of PO_4^{3-} while ICP manifested 0.01 mg/L of Ca and 0.03 mg/L of Si.

Zimmer Biomet OsseoTite presented 11.20 at% of C, 16.76 at% of N, 17.45 at% of O, 1.50 at% of Na, 2.50 at% of Ca, and 52.09 at% of Ti on EDAX. XPS manifested 28.97 at% of C1s, 2.46 at% of N1s, 52.98 at% of O1s, and 15.60 at% of Ti2p at the apex while 31.64 at% of C1s, 1.82 at% of N1s, 50.03 at% of O1s, and 16.51 at% of Ti2p were at the neck. 0.031 mg/L of NO_2^- and 0.041 mg/L of NO_3^- were found on IC, and 0.02 mg/L of Ca was revealed on ICP.

Nobelbiocare NobelActive displayed 3.24 at% of C, 11.79 at% of N, 46.27 at% of O, 0.45 at% of Magnesium (Mg), 6.67 at% of P, 0.19 at% of Ca, and 31.38 at% of Ti on EDAX. XPS exhibited 25.08 at% of C1s, 2.24 at% of N1s, 53.14 at% of O1s, 7.36 at% of P2p, and 12.18 at% of Ti2p at apex while 25.31 at% of C1s, 1.30 at% of N1s, 53.43 at% of O1s, 5.94 at% of P2p, and 14.03 at% of Ti2p were revealed at the neck. IC showed 0.446 mg/L of SO_4^{2-}, 0.001 mg/L of NO_3^-, and 0.393 mg/L of PO_4^{3-}. 0.14 mg/L of P was presented on ICP.

Nobelbiocare NobelReplace exhibited 1.58 at% of C, 9.15 at% of N, 42.57 at% of O, 6.07 at% of P, and 40.63 at% of Ti on EDAX. XPS demonstrated 20.20 at% of C1s, 2.05 at% of N1s, 56.42 at% of O1s, 8.29 at% of P2p, and 13.04 at% of Ti2p at the apex while 21.93 at% of C1s, 2.20 at% of N1s, 55.15 at% of O1s, 9.12 at% of P2p, and 11.62 at% of Ti2p were presented at the neck. IC showed 0.007 mg/L of Cl^-, 0.456 mg/L of SO_4^{2-}, 0.009 mg/L of NO_3^-, and 0.392 mg/L of PO_4^{3-}. ICP revealed 0.14 mg/L of P and 0.01 mg/L of Si.

Bicon Short manifested 31.31 at% of C, 35.42 at% of O, 0.42 at% of Mg, 1.78 at% of Al, 7.61 at% of P, 7.61 at% of Ca, and 12.42 at% of Ti on EDAX. XPS showed 23.67 at% of C2s, 12.85 at% of Ca2p, 1.01 at% of N1s, 4.76 at% of Na1s, 47.42 at% of O1s, and 10.28 at% of P2p at the apex while 25.18 at% of C1s, 13.26 at% of Ca2p, 1.88 at% of Na1s, 47.83 at% of O1s, and 11.85 at% of P2p were presented at the neck. 0.007 mg/L of Cl^-, 0.069 mg/L of NO_2^-, 0.031 mg/L of SO_4^{2-}, 0.078 mg/L of NO_3^- were displayed on IC. ICP detected 5.26 mg/L of Ca, 0.04 mg/L of Na, 0.01 mg/L of Ni, 0.04 mg/L of Mg, 0.17 mg/L of Al, 1.53 mg/L of P, and 0.12 mg/L of Si.

Hydrophilicity

Among the fifteen different implant systems, only Cowellmedi INNO implant showed immediate hydrophilicity when the implant was in contact with DI water (Table 8).

Cowellmedi INNO	**Straumann Roxolid**	**Neodent CM DRIVE**
		

ADIN Touareg-S Spiral	Alpha Bio Tec SPI	MIS Lance
		

S.I.N Unitite	Ankylos C/X implant	Xive S Plus
		

AstraTech Implant system EV-Osseospeed	BioHorizons Tamper Evident	Zimmer Biomet OsseoTite
		

Nobelbiocare NobelActive	Nobelbiocare NobelReplace	Bicon Short
		

Table 8. Result of Hydrophilicity test.

Discussion

Dental implant is widely accepted as a reliable treatment for fully and partially edentulous patients due to its excellent biomechanical properties. A key to implant success largely depends on osseointegration between implant and surrounding bone. Herein, various methods to facilitate its osseointegration have been investigated throughout the world. Since pure Titanium, the core material of implant, is bioinert, numerous attempts to modify its surface have been made.

Implant surface modification can be performed through subtractive and additive methods. Subtractive treatments include sandblasting, acid-etching, dual acid-etching, sandblasting with large grit and acid etching (SLA), and laser peening while the examples of additive method are anodization, fluoride surface treatment, nanostructured surface, spraying plasma, coating sol-gel, sputter deposition, electrophoretic deposition, biomimetic precipitation, and coating of bioactive drugs or osteogenic agents [6]. The aforementioned methods are intended to modify surface properties such as hydrophilicity surface topography, composition [8,13,21]. Thus, these three surface properties of fifteen commercially available implant systems were verified through scanning electron microscopy (SEM), energy disperse X-ray (EDAX), X-ray photoelectron spectroscopy (XPS), ion chromatography (IC), inductively-coupled plasma-atom (ICP), and hydrophilicity test.

The presence of certain elements, such as Fluorine(F), Arsenic (As), Aluminum (Al), Sulfur (S), Silicon (Si), Technetium (Tc), Nickel (Ni), Potassium (K), and Zinc (Zn), may be considered as impurities, possessing potential risk for implant success. For example, Fluorine can be detected when abstergent is not completely removed. Arsenic is a carcinogenic element, so it is better not to be remained. Sulfur can be detected when cutting fluid or etchant is insufficiently washed. Aluminum comes from Aluminum oxide which is commonly used as a blasting material to create roughness on implant surface. These impurities are remained due to insufficient washing process.

On the other hand, the application of Magnesium (Mg), Sodium chloride (NaCl), and Calcium (Ca) are speculated to be advantageous for osteogenic process. A study by Sul et al. reported that implants with magnesium derive higher removal torque values (RTV) [22]. In addition, when implant is maintained in isotonic solution of 0.9% Sodium Chloride, osseointegration can be accelerated, and area of bone-to-implant interface can be increased [19]. Furthermore, the effect of calcium-coated implant surface on osseointegration is well-established by several studies; thus, a number of implant system have adopted calcium coating, such as calcium phosphate crystal, on purpose of stimulating osseointegration [7,9,11]. Among the implants investigated in the present study, seven implant systems, including Cowellmedi INNO, Straumann Roxolid, S.I.N Unitite, Anklyos C/X Implant, Zimmer Biomet OsseoTite, Nobelcare NobelActive, and Bicon Short, demonstrated calcium coating.

It is noteworthy that Cowellmedi INNO implant was the only implant system that exhibited instantaneous wetting when contacted with deionized water. Also, its surface was the only one without nano-roughness as presented via SEM image in Table 2. Some studies speculated that the hydrophobic property of implants may be due to air entrapped inside the micropores, and the entrapped air can be involved in approximately three quarters of the total surface area contacting with fluid: thus, a small portion of implant surface may exhibit the initial wetting with blood when the implant is placed clinically [17,18].

Within the limitation of this study, it is assumed that hydrophilicity can be achieved through chemical composition of the implant surface rather than surface roughness. In addition, further studies are necessary to verify the application of hydrophilic implant as a potential carrier of osteoinductive materials such as bone morphogenetic protein 2 (BMP-2).

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