COMPARISON OF SURFACE ROUGHNESS AND ELEMENTAL ANALYSIS OF DIFFERENT MINI IMPLANT SYSTEMS

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ABSTRACT

Mini implant systems are used for orthodontic anchorage and are very important for the success of orthodontic treatment. Surface chemistry, surface topography and roughness of mini implant. Changes in design of mini implant not only affect stability but also the properties. Unwanted material contamination on implant surfaces affects osteointegration, stability and success. The purpose of this study was to compare different mini implant systems including their surface morphology, elemental composition, surfaces and roughness.

Six types of mini implants from six major companies were included in the study. Mini implants were analyzed with scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS) and infinite focus microscopy (IFM).

All mini implants showed an acceptable shape and surface morphology. However, at the higher magnification, small cavities and protrusions were observed on surfaces of some mini implant systems. Various elements which are not related to the metal composition of mini implant were detected on these mini implants. Statistically significant differences were found in terms of amounts of elements among mini implant brands.

In terms of surface characteristics, mini implants were affected by the mechanical manufacturing, packaging, sterilization and handling process. We higly recommend Alicona technique for evaluation of surfaces and the roughness in all implant surface studies. Surface roughness can increase the degree of osseointegration and it can lead to complications during removal of mini implants in orthodontics.

Key Words: *Mini implant, roughness, elemantal analysis.*

INTRODUCTION

Orthodontic anchorage is defined as resistance to undesired tooth movement.[1] Planing of anchorage is very important for the success of orthodontic treatment.[2] Any uncontrolled reactive force can have an undesirable effect on the result of the orthodontic treatment.[3] Therefore, use of mini implants as a skeletal anchorage appliance is gaining popularity day by day.[4] Atraumatic insertion function, the possibility of applying immediate loading are some reasons for their popularity.[5] Mini implants are generally fabricated from commercially pure titanium or grade V titanium alloy.6 Titanium alloyed mini implants, have excellent biocompatibility.[7]

Unlike dental implants, mini implants are manufactured in smaller size and titanium alloy is preferred because of its higher strength relative to commercially pure titanium.[8] The surface properties of mini implants are also as important as production of titanium alloy for its stability. In contrast to dental implants, mini implants commonly have smooth surface. Although some companies produce sand blasted and etched surfaced mini implants, this doesn't provide the osseointegration ability, but increases the biocompaibility.[9]

Mini implants are desired to be removed easily by the end of orthodontic treatment but treated surface make removal more difficult.[9,10] Consaquently, mini implant osteointegration is not expected and many similar studies have reported that stability of mini implant is based on the bone and its groove mechanical contact.[2] Therefore, insertion torque of mini implants indicate the level of primary stability.[11] However,

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osteointegration is not highly desirable around mini implants, because it can complicate the mini implant removal.[12] On the other hand, recent studies have shown that the osteointegration does occurs between mini implant and bone tissue altough mini implants have smooth surfaces.[13]

Cells of osteointegration process can distinguish meticulously due to surface chemistry, surface topography and roughness of mini implant.[14] This indicates that changes in design of mini implant affect the stability of implant.[15] Also, many studies have reported the effects of surface property on osteointegration in bone.[16] The implant surface can change noticeably due to manufacturing conditions. The existence of adventitious contaminants at the surface of the implant may also affect the response of the human body. However the effects of specific contaminants at a low concentration on the body are not well known.[17] For that, several variables related to properties of implant surfaces are investigated in clinical and animal studies and as a result; spesific elements like plumbum (Pb) and zinc (Zn) which are not normally presented on the surface of a titanium implant are blamed for the failure of an impIant.[18]

The literature does not have comprehensive data on surface and elemental composition of mini implants.[6] Considering that most of manufacturers provide nonsterile mini implants[19], the possibility of contamination of mini implant surface may occur during the handling or packaging process. Clinicians can choose suitable implant brands according to the requirements of the treatment[20], yet they do not have any guidelines, except for the manufacturer's recommendations, about selection of implant system.

However there is not a reliable clinical evidence to support any implant brand.[21] Before the utilization, analyzing the surface of mini implants shows it to be notably reasonable.[22] For this reason, carefully examination of the implant surface about unwanted chemical elements and surface properties are extremely important.[17] In addition to these mechanical concerns, unwanted chemical elements and metal residues on the surface of mini implant may lead to harmfull effect on the body, such as induced adverse tissue reactions and immunological responses.[23] In the present study, six different commercially available mini implants (PSM, American Orthodontics, Orthoeasy, AbsoAnchor, Tomas, Mitos) have been investigated in terms of surface composition and characteristics.

The purpose of this study was to compare mini implant specimens in terms of the surface chemistry, morphology and roughness. Scanning electron microscopy (SEM) was used to image the surface macro-microstructure and claning of surface (existance of metal residues during production) and also energy dispersive X-ray spectroscopy (EDS) was used to investigate localized residues of elements which are believed to be contaminats.[24] In addition surface topograpies and roughnesses of mini implants were analyzed using infinite focus microscopy (IFM - Alicona Imaging/ Graz;Austria).[25]

METHODOLOGY

Six types of mini implants were purchased from six major campanies: American Orthodontics (1,5x8 mm, The Aarhus System Mini implants, Sheboygan, WI USA), Tasarımmed (1,6x6 mm, Mitos, Istanbul, Turkey), Dentos (1.4x8 mm, Abso Anchor System, Daegu/ Korea), Dentarum (1,6x8 mm, TOMAS System, Ispringen/ Germany), Forestadent (1,7x8 mm, Ortho Easy Pin, Pforzheim / Germany), PSM (1.5x9 mm, Benefits Mini İmplants, Tuttlingen/ Germany). All mini implants were based on grade 5 titanium alloy (Ti6Al4V) and had smooth surface according to the manufacturer directions. Packages of all mini implants were opened at the start of performing the analysis. They were handled very attentively in order to avoid contamination during further procedures. Mini implants brands investigated in this study are shown in Table 1.

SEM and EDS

The surface morphology was analyzed with SEM (Zeiss Evo LS15, Jena, Germany) at 20 kV. All mini implants were analyzed according to the same instrumentation protocol and they were taken directly from their original package from supplier. Mini implants were handled by plastic attachment and gloves to preserve from instrumental stratching. The SEM investigations were performed on middle 1/3 of each mini implants. The system vacuum pressure was maintained 1x10-6 mbar and gun vacuum pressure was maintained at 1x10-7 mbar. Surface images were captured by a computer and evaluated using Smartsem software. Magnification ranged from 50-150.

Surface chemical components were evaluated by means of energy-dispersive spectrometer (EDS). For each specimen, five spectras from randomly selected locations were obtained. 20 kV voltage was utilized to identify the peak and background ratio for elements. Working distance for EDS analysis was 8.5 mm. Data were analyzed by One Way ANOVA followed by Tukey's test to determine differences regarding the amount of the elements in each mini implant brand. Significance level was at 0.05.

Surface Roughness

The surface roughness was quantified and vizualized using infinite focus microscop imaging (Alicona Graz/Austria). Surface roughness measurement was made on three different grooves (upper, middle and lower regions birds) for each mini implant at 100 tilt.

Magnification value was 50 times during the process. For each groove of mini implants, a histogram with 15 measures were obtained. Four parameters (Ra, Rt, Rz and Rsm) were used in the histogram. Ra is the average profile roughness, Rt is the maximum peak to valley height of roughness profile, Rz is the mean peak to valley height of roughness profile and Rsm is the mean spacing of profile irregularities of roughness profile. Ra, Rt, Rz and Rsm were obtained from three grooves for the mini implant. The arithmetic mean values of the surface roughness within the sampling areas were determined. Statistical analysis was performed by the One Way ANOVA test followed by Tukey's test. Significance level was at 0.05.

RESULTS

SEM and EDS Investigation

All mini implants were imaged at various magnifications from 50x to 150x. Six measurements on each mini implants (3 for upper half and 3 for lower half at

TABLE 1: INVESTIGATED MINI IMPLANTS BRANDS

Name of System	Type of Material	Type of Surface	Manufacturer
Aarhus System	TiAl6V4	Smooth	Amerikan Orthodontics
Abso Anchor	TiAl6V4	Smooth	Dentos
Tomas System	TiAl6V4	Smooth	Dentarum
Ortho Easy Pin	TiAl6V4	Smooth	Forestadent
Benefits Mini-İmplant	TiAl6V4	Smooth	PSM
Mitos	TiAl6V4	Smooth	Tasarımmed

TABLE 2: EDS FINDINGS ON SURFACE ELEMENTS (WEIGHT PERCENT%) OF ALL MINI IMPLANTS. MUTIPLE COMPARISONS WITHIN GROUPS (ONE WAY ANOVA AND TUKEY'S TESTS) (NA, NOT APPLICABLE: INDICATES VALUE OF ZERO, SO COMPARISON COULD NOT BE MADE.) (TI, TITANIUM; AL, ALUMINUM; O, OXYGEN; C, CARBON; FL, FLUORINE; FE, IRON; NA, SODIUM; SI, SILICONE ; CL, CHLORINE; K, POTASSIUM; N, NITROGEN; CR,CHROME; NI, NICKEL; MG, MAGNESIUM; CU, COPPER; CA; CALCIUM; CS, CESIUM; S, SULFUR.)

Mini implants Elemets	Benefits Mini Implant	Mitos	Aarhus System	Abso Anchor	Tomas System	P value
Tİ	72,125±6,5	38,808±17,2	43,978±26	82,898±10,3	74,565±31,4	0,013*
Al	2,427±2,348	3,577±1,013	1,962±0,964	6,365±1,529	1,640±0,197	<0,001*
V	NA	NA	NA	3,18±0,011	3,63±0,023	-
C	2,555±0,964	9,700±7,902	14,605±5,119	4,075±2,947	17,387±4,036	<0,001*
O	24,345±11,150	46,845±8,095	30,185±6,078	21,815±2,546	23,958±6,182	0,003*
Fe	NA	0,605±0,134	25,450±0,636	0,448±0,038	NA	0,067
Na	NA	18,603±7,844	7,230±1,743	1,862±0,06	1,780±0,289	0,143
Si	NA	0,855±0,686	0,890±0,156	0,145±0,050	1,800±0,976	0,162
Cl	NA	3,207±1,413	8,413±2,442	NA	1,273±0,627	0,532
K	NA	1,340±0,653	1,200±0,340	NA	1,143±0,406	0,88
N	NA	NA	9,33	NA	NA	—
Cr	NA	NA	7,02	NA	NA	—
Ni	NA	NA	3,28	NA	NA	—
Mg	NA	NA	1,28	NA	NA	—
Cu	NA	0,49	NA	NA	NA	—
Ca	NA	0,660±0,028	NA	NA	0,922±0,031	0,333
Ce	NA	NA	NA	NA	1,06±0,02	—
S	NA	8,295±1,052	0,725±0,007	NA	0,670±0,01	0,667
Fl	9,2	NA	NA	NA	NA	—

TABLE 3: COMPARISON OF ROUGHNESS DIFFERENT MINI IMPLANT SYSTEMS(ANOVA AND TUKEY'S TEST). RA IS THE AVERAGE PROFILE ROUGHNESS, RT IS THE MAXIMUM PEAK TO VALLEY HEIGHT OF ROUGHNESS PROFILE, RZ IS THE MEAN PEAK TO VALLEY HEIGHT OF ROUGHNESS PROFILE AND RSM IS THE MEAN SPACING OF PROFILE IRREGULARITIES OF ROUGHNESS PROFILE

Roughness Parameter	Benefits Mini İmplant	Mitos	Aarhus System	Abso Anchor	Tomas System	Ortho Easy Pin	P value
Ra	0,427±0,188	0,240±0,152	0,280±0,036	0,527±0,176	0,210±0,017	0,363±0,041	0,003*
Rt	3,090±2,139	1,600±1,134	1,453±0,392	5,913±3,823	1,397±0,255	2,780±0,807	0,007*
Rz	1,970±1,182	0,870±0,537	0,890±0,147	2,733±1,482	0,970±0,142	1,443±0,320	0,007*
Rsm	122,317±19,525	65,197±25,635	81,297±30,881	63,160±25,795	52,073±20,42	54,130±33,053	0,484

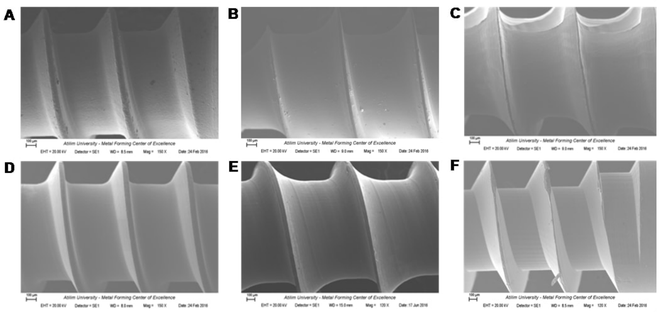

Fig 1: Maginification is 120x. A) Aarhus System(American Orthdontics); B) Mitos (Tasarımmed); C) Ortho Easy Pin (Forestadent); D) Benefits Mini-İmplant (PSM); E) Tomas System (Dentarum); F) Abso Anchor (Dentos).

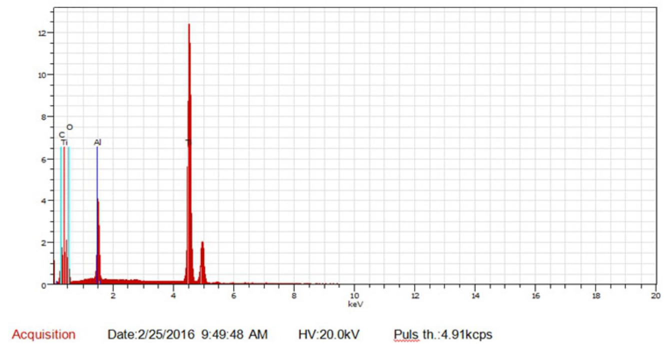

Fig 3: SEM images of the mini implant type Abso Anchor(Dentos), maginification is120x., Representative graphic of EDS of metal particle in (C: carbon: oxygen Ti: titanium, Al: aluminum).

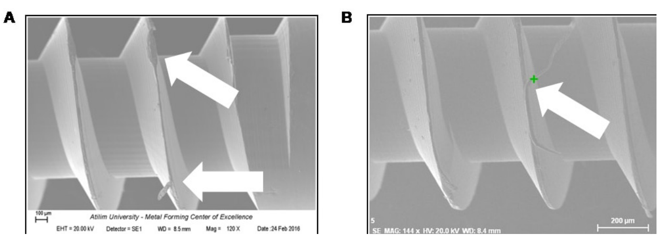

Fig 2: A) SEM images of the mini implant type Abso Anchor(Dentos), maginification is120x. torn metal particle typical machined surface is shown white arrows (C: carbon: oxygen Ti: titanium, Al: aluminum). B) SEM images of the mini implant type Abso Anchor(Dentos), maginification is120x. Fractures were observed in the edge of the grooves of mini implant shown with white arrow and green point; (C: carbon: oxygen Ti: titanium, Al: aluminum).

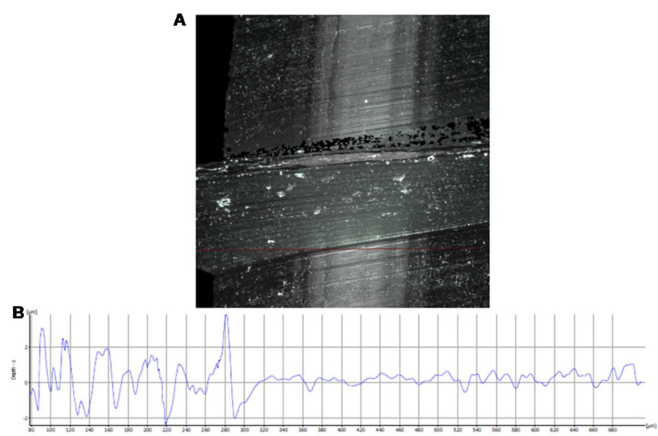

Fig 4: Roughness measurements from infinite focus microscopy. A, measured surface of mini implant; B, measurement profile, filter size Lc 80.00 µm.

threaded surface) were examined by EDS analysis. At low magnification all mini implant demonstrate a well shaped implant surface homogeneity and acceptable surface morphology. However at the higher magnification, differences were seen in topography of the mini implants (Fig 1). Small cavities and protrusions were observed on surface of Aarhus System(American Orthdontics), Tomas System (Dentarum), Mitos (Tasarımmed) and Abso Anchor(Dentos). Sizes of these defects (cavities and protrusions) were detected within micron levels.

However, this micronity means irregularity on surface structure of the mini implants. In addition, fractures were observed in the edge of the grooves of Abso Anchor (Dentos) at 120x (Fig 2a), also foreign particles were determined on the mini implant (Fig 2b). EDS analysis showed these particles to be composed of Ti, Al and V metals that are used in manufacturing process of mini implant. Consequently these were torn metal particles typical of machined surface. Fig 3 shows local analysis by EDS. The surface elemental composition of all mini implants and statistical significant findings are shown in Table 2.

All six mini implant systems showed presence of titanium, aluminium, oxygen and carbon in different amounts (Table 2). However, titanium amounts of Abso Anchor mini implant was statistically greater than Mitos mini implant and aluminium amount of Abso Anchor mini implant was statistically greater than Aarhus System, Benefits Mini-Implant and Tomas System mini implants. Oxygen amounts of Mitos mini implant were statistically higher than the other mini implant brands except Aarhus System. Altough carbon proportion of Aarhus System and Tomas System mini implants were statistically higher than Benefits Mini-Implant, Abso Anchor and Ortho Easy Pin mini implants, no statistically significant difference was observed on carbon proportion of Mitos mini implant. Iron, sodium, silicone, chlorine, potassium, calcium and sulfur elements were determined in some mini implants (Table 2). However, there was no statistically significant difference between proportion of these elements of mini scews. Otherwise nitrogen, chrome, nickel and magnesium only were found in Aarhus System mini implant. Fluorine, copper and cesium were only observed in Benefits Mini-Implant, Mitos and Tomas System.

Infinite Focus Microscope Imaging Investigation

Roughness measurements were performed by Alicona infinite focus microscope as shown in Fig 4. Three measurements were examined for different locations of mini implants (upper, middle and lower regions). Four parameters (Ra, Rt, Rz and Rsm) were used in the histogram for statistical comparison as shown in Table 3. Significant differences in roughness were found in Abso Anchor and Tomas System for Ra (average profile roughness) and Rt (the maximum peak to valley height) values. Abso Anchor mini implants showed statistically higher roughness than Tomas System. Meanwhile statistically significant difference between Abso Anchor and Mitos for Rz (mean peak to valley height) value is reported. However, there is no statistical significant difference in Rsm (mean spacing profile irregularities) values. Consequently, the results showed that Abso Anchor had the highest roughness value.

DISCUSSION

Surface quality is extremely critical in mini implants because it provides significant information about performance and success of the material in the environment in which it is intended to be functional. The surface characteristics of mini implants effect the tissue reaction at the mini implant / tissue interface. On the other hand surface characteristics of unused dental implant systems have been reported by many investigators in several recent SEM studies.[26] Even so, a few studies were reported about basic material properties of mini implant in literature. Similar studies have also been made for retrieved mini implants.[27,28] However surface properties of unused mini implants are not well documented in the literature.

In the present study, different mini implants brands were analyzed by using SEM, EDS and IFM to demonstrate their surface characteristics, elemantal composition and roughness. The SEM results indicate small cavities and protrusions in the surface profiles of all mini implants. Especially one interesting result was the existence of fractures and multiple torn particles of Tomas System (Dentarum). These defects could be attributed to manufacturing process and can be a origin for electrochemical attack when mini implants are inserted in the body.29 Titanium alloys have a high corrosion resistant because of the stable passive titanium oxide layer on the surface.[6] When the persistence oxide layer breaks down, titanium can be as corrosive as many other base metals.[30] This corrosion can lead to release of many metals into tissues.[31] When these metals are released, they can cause potentially toxic substances.[32] Wetterhahn et al reported that, the corrosion products can lead to allergic reactions such as perioral stomatitis, gingivitis, extraoral eczematous rashes and may be carcinogenic.[33] However, corrosion that is caused by these defects can lead to poor mechanical strength. Surface micro-irregularity can cause failure of stability and have a negative effect on success of material.

Without quantitative and numeric analyses, only morphologic examinations are able to be performed by SEM.[27] Therefore, EDS was performed for quantitative analysis in this study. The elemental compositions of an implant surface depends on manufacturing process, machining and sterilization procedures.[17]

The EDS spectra provides data in weight percentages of elements for six mini implants. This result revealed the presence of titanium, aluminium, oxygen and carbon in all commercially available systems. Although Ti, Al and V are base elements for grade 5 titanium alloy, in this study, vanadium peak was masked in several mini implants. We also detected other elements in trace amounts. The other elements were Fe, Na, Si, Cl, K, N, Cr, Ni, Mg, Cu, Ca, Ce, S and Fl. All six mini implants indicated different elemental composition.

Elemental contamination on the mini implant surfaces is usually caused by the production process (including lubricants, detergents or other specific chemical compounds), sterilization, packing, handling process and contact with air in the environment.[17] When contamination occurs with the air, hydrocarbons or particles containing carbon and oxygen are absorbed by the surface. However the surfaces can not be prevented from this organic contamination (including oxygen, carbon and nitrogen elements).[17] Vezeau et al have reported similar reviews in their mini implant study.[34] Contamination can affect surface quality even in presence of trace amounts compared to the total bulk of the implant.[35] However there is actually few reports in the literature about the effects of specific contaminants in small quantities.[17]

Chin et al detected trace of N, Ca, Fe, Cr, Cu, Pb, Zn, and Si on mini implants surface in their elemental study. They reported that surface contamination is an apparent problem.[36] As mentioned before, these elements on surface of unused mini implants may be toxic and allergic. For instance, Heinemann et al have reported that great amounts of vanadium has acute and chronic toxicity.[37] However, there is agreement about the carefull control of implant surface and the importance of protecting the surface from unwanted contaminants for quality of device.[17]

In addition, surface roughness were investigated and compared statistically in this study. Surface roughness is also essential for the bone / implant contact and bone reaction.[38] Altough it is the most important factor for osseointegration in dental implants, smooth surface on mini implants is desirable property for orthodontic procedures. Because perfect osseointegration can lead to complications (e.g. mini implant fracture) during removal of mini implants in orthodontics.[12] Also unlike the dental implants, function duration of the mini implant is less than dental implant. Hence, mini implants are fabricated to provide mechanical retention for stability.

The common parameters for the surface roughness are roughness average (Ra) and maximum height of profile (Rz) for surface texture.[39] Four parameters (Ra, Rt, Rz and RSM) were evaluated for surface roughness of mini implants in this study. Roughness measurements were compared among six mini implant systems and differences in Ra-Rt values were found statistically significant between Abso Anchor and Tomas System. Also Rz values of Abso Anchor and Mitos systems were statstically significant. Surface roughness was classified by Wennerberg and Albrektsson as follows: smooth surface: roughness <0.5 µm, minimally rough surface=0,5-1,0µm, moderately rough surface=1-2µm and rough surface>2.0µm[40]. According to Wennerberg and Albrektsson roughness classification, our study showed that not only Abso Anchor mini implant system had minimally rough surfaces in general terms (0,527±0,176) but also this system had rougher surfaces than the other five systems in the present study. Additionally, only Abso Anchor mini implant system surfaces were reported as non-smooth, among these six systems whereas Tomas mini implant system had the smoothest surface.

The success of orthodontic mini implants relates on the practical metallurgy in their production process. It requires a great quality alloy and proper handling of material. During the manufacturing process of the mini implants, products must be prevented from metallurgical contamination.[41] The contamination of the mini implant surface can be a cause of clinical failure.[42] However, further studies are required on contamination, biocompatibility and stability of mini implants.

In conclusion, all of mini implant brands in the present study exhibit a well implant-shape, surface homogeneity and acceptable surface morphology. However micro-irregularities were detected on surfaces. EDS analysis indicated that all of mini implants showed different elemental compositions in addition to titanium, aluminum, vanadium, oxygen and carbon.

Manufacturing, packaging and handling processes are the possible reasons of the elemental contaminations. According to infinite focus microscope data, one of the mini implant brand (Abso Anchor) showed minimally rougher surface. Surface roughness increase the degree of osseointegration but it can also lead to complications during removal of mini implants in orthodontics.

Although we report and higly recommend the Alicona technique for evaluation of surfaces and the roughness in our mini implant study, it is very rare in literature. Few studies were published about effects of the low concentration contaminants on success of mini implant function and surrounding tissue of the implants in literature, thus further studies are required.

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