EVALUATION OF BONE RESPONSE BY RESONANCE FREQUENCY ANALYSIS OF ANODIZED IMPLANTS

Hyun-Ki Roh, D.D.S., M.S.D., Seong-Joo Heo, D.D.S., Ph.D., In-Chul Rhyu, D.D.S., Ph.D.*
Department of Prosthodontics, Graduate School, Seoul National University
* Department of Periodontics, Graduate School, Seoul National University

Statement of problem. Resonance frequency analysis has been increasingly served as a non-invasive and objective method for clinical monitoring of implant stability. Many clinical studies must be required for standardized data using RFA.

Purpose. This study was performed to evaluate RFA value changes in two anodized implant groups.

Material and method. Among a total of 24 implants, twelve screw shaped implants as a test group (H2-R8.5) were manufactured, which had a pitch-height of 0.4 mm, an outer diameter of 4.3 mm, a length of 8.5 mm, and external hexa-headed, were turned from 5 mm rods of commercially pure titanium (ASTM Grade IV, Warantec Co., Seoul, Korea), and another twelve implants as a control group were Brånemark Ti-Unite MK4 (diameter 4.0 mm, length 8.5 mm). Each group was installed in tibia of rabbit. Two implants were placed in each tibia (four implants per rabbit). Test two implants were inserted in right side and control two in left side. ISQ values were measured using Osstell™ (Integration Diagnostics Ltd. Sweden) during fixture installation, and 12 weeks later and evaluated the RFA changes.

Results. Mean and SD of baseline ISQ values of test group were 75.0 ± 3.4 and 68.7 ± 8.1 for control group. Mean and SD of ISQ values 12 weeks after implant insertion were 73.2 ± 4.7 for test group and 72.6 ± 3.9 for control group.

There were no statistically significant differences between groups in ISQ values after 3months ($P>0.05$). From the data, RFA gains after 3 months were calculated, and there was statistically significant difference between groups ($P<0.05$).

Conclusion. Although there were RFA changes between groups, implant stability after experimental period shows alike tendency and good bone responses.

Key Words

Resonance frequency analysis (RFA), Implant stability, Anodized implant surface

For successful implant therapy, it is essential to achieve well-maintaining osseointegration. Osseointegration is a continuing structural and functional coexistence, possibly in a symbiotic manner, between differenciated, adequately remodeling, biologic tissues and strictly defined and controlled synthetic components, providing long lasting, specific clinical functions without rejection mechanics. The importance of implant surface properties for successful osseointegration was first pointed out by Albrektsson et al.[1] Surface properties are important for and may be used to facilitate tissue integration. However, a number of questions have been posed regarding the important role of the titanium implant surface properties during 'dynamic build-up' of the osseointegration process. Interest in titanium implant surface oxide properties has increased with the development of methods to characterize such surfaces. Moreover, the possibility of surface modification of titanium implants to improve tissue responses is an outstanding feature in metal implantology research. In the air at room temperature, the surface of titanium is covered spontaneously by an oxide layer, which is 1.5-10 nm in thickness.[2] It was defined that the oxide layer has low level of electronic conductivity,[3] great thermodynamic stability,[4] and low ion-formation tendency in aqueous environments.[5] These properties may be the reasons for the excellent biocompatibility of titanium implants.

Recently, an electrochemical procedure for modifying the Ti surface was proposed, which has since attracted much attention. By applying a positive voltage to a Ti specimen immersed in an electrolyte, anodic oxidation (or anodization) of Ti occurs forming a TiO_2 surface layer. When the applied voltage is increased to a certain point, a micro-arc occurs resulting from dielectric breakdown of the TiO_2 layer. At the moment the dielectric breakdown occurs, Ti ions in the implant and OH ions in the electrolyte move in opposite directions very quickly to form TiO_2 again. This process is generally referred to as micro-arc oxidation (MAO) or plasma electrolysis.[6] The newly formed TiO_2 layer is both porous and firmly adhered to the substrate, which is beneficial for the biological performance of the implants.

Recent studies on the biological response of Ti implants demonstrated the MAO process constitutes one of the best methods of modifying the implant surface.[7] However, further research is necessary for the complete characterization of the oxide layer and identification of the optimum conditions for the MAO process.

Resonance frequency measurements can be related to the stiffness of an implant in the surrounding tissues and also to the level of the surrounding bone. Primary implant stability is related to bone quality, that is, the density of the surrounding bone and the height of the bone level and surgical technique. Secondary implant stability can be increased by bone formation and remodeling at the implant/bone interface. Further investigations using resonance frequency analysis are required to study the structural changed at the implant-tissue interface during healing and the influence of variables including boned quality and quantity. This may enable desirable levels of stability at fixture placement and the degree of healing prior to loading to be established to ensure a successful long-term outcome. Nowadays, resonance frequency analysis (RFA) technique has been increasingly served as a sensitive and objective tool for clinical monitoring of implant stability.[8,9] However, for the precise evaluation of individual implant stability or comparison with other implants in various clinical conditions, standardized baseline data using RFA are urgently required.[10] Therefore, more clinical studies are needed to elucidate resultant implant stabilities in such specific conditions as identification of implant status at risk for implant failure, individualization of healing periods after implant placement and so on.

In present study, it was planned and performed that RFA value changes with time would be observed after implants placement in rabbits.

The aims of this study were to evaluate the RFA values of two anodized implant groups with different primary stability immediately after implant placement and 12 weeks later.

MATERIALS AND METHODS

2.1. Implant preparation : design and surface oxide

Among a total of 24 implants, twelve screw shaped implants as a test group (H2-R8.5) were manufactured, which had a pitch-height of 0.4 mm, an outer diameter of 4.3 mm, a length of 8.5 mm, and external hexa-headed, were turned from 5 mm rods of commercially pure titanium (ASTM Grade IV, Warantec Co., Seoul, Korea), and another twelve implants as a control group were Brånemark Ti-Unite MK4 (diameter 4.0 mm, length 8.5 mm). Surface oxides used in the test group were prepared with the use of a DC power supply in electrolyte solution.

2.2. Micro-arc Oxidation (MAO)

Test implants (H2-R8.5) were prepared using MAO methods at the galvanostatic mode.

MAO of the test group was carried out in an aqueous electrolyte by applying a pulsed DC field to the specimen with a frequency of 660 Hz. The electrolyte was prepared by dissolving 0.15 mol calcium acetate monohydrate {$Ca(CH_3COO)_2 \cdot H_2O$} and 0.02 mol calcium glycerophosphate ($CaC_3H_7O_6P$) in de-ionized water. High range of DC 300 Voltage were applied to the specimens, with each treatment lasting 3 minutes. All MAO processing was carried out in a water-cooled bath made of stainless steel, using a stainless steel plate (100 × 60 × 1 mm) as the counter electrode.

2.3 Animals and surgical technique

6 mature (average age 10 months old weighing 3-3.5kg) New Zealand white rabbits of both sexes were included in this study. During surgery, animals were anaesthetized with intramuscular injections of Ketamine 10mg/kg (Yu-han Co., Seoul, Korea) and Rompune 0.15mg/kg (Bayer Korea Co., Seoul, Korea). Prior to surgery, the shaved skin was carefully washed with a mixture of iodine and 70% ethanol. Local anesthesia with 1.0ml of 5% lidocaine including 1:100,000 epinephrine (Yu-han Co., Seoul, Korea) was administered, at the tuberosity tibiae part of the bone where the incision was planned, under aseptic conditions. The skin and fascial layers were opened and closed separately. The periosteal layer was gently pulled away from the surgical area and was not re-sutured. During all surgical drilling sequences, low rotary drill speeds not exceeding 1000rpm and profuse saline cooling were used. Drilling and fixture insertion was performed following surgical protocol of the Oneplant system® (Warantec Co., Seoul, Korea).

Two implants were placed in each tibia (four implants per rabbit), which penetrated one cortical layer only. Test two implants were inserted in right side and control two in left side, separated in 10 mm each other. The animals were kept in separate cages and immediately after surgery, were allowed to be fully weight-bearing. After a follow-up period of 12 weeks, the animals were sacrificed in CO_2 chamber.

2. 4. Resonance frequency measurements

Directly after implant insertion, the base line RFA was monitored on the implants.

At the day of sacrifice, i.e. 3 month after implant insertion, the RFA was again tested. This method is a non-destructive technique that demonstrates the implant stability in terms of interfacial stiffness (Hz). The frequency response of the system was measured by attaching the transducer to a screw implant.

Osstell™ (Integration Diagnostics Ltd. Sweden) was used for implant stability measurements in this study. The transducers were orientated perpendicular to the long axis of tibia and were tightened by hand. Results were represented as an ISQ (Implant Stability Quotient, 1-100).

2.5. Statistics

Data are presented as means ± SD. One-way analysis of variance (ANOVA) was used for statistical analysis of the data. Differences were considered statistically significant at $P<0.05$.

RESULTS

Mean and SD of baseline ISQ values of test group were 75.0 ± 3.4 and 68.7 ± 8.1 for control group. Mean and SD of ISQ values 12 weeks after implant insertion were 73.2 ± 4.7 for test group and 72.6 ± 3.9 for control group.(Table I, II and III)

There were no statistically significant differences between groups in ISQ values after 3 months.

Table I. RFA for H2-R8.5 and Ti-Unite at fixture installation

	0 week (in ISQ value)	
	H2-R8.5	Ti-Unite MK4
	81	81
	76	74
	76	79
	77	76
	77	71
	76	64
	77	60
	73	74
	71	61
	68	63
	73	64
	75	57
Mean	75.0	68.7
SD	3.4	8.1

Table II. RFA for H2-R8.5 and Ti-Unite after 12 weeks

	12 weeks (in ISQ value)	
	H2-R8.5	Ti-Unite MK4
	69	78
	75	73
	81	78
	75	67
	82	75
	68	76
	71	69
	67	67
	75	70
	73	70
	71	74
	71	74
Mean	73.2	72.6
SD	4.7	3.9

Table III. RFA change for H2-R8.5 and Ti-Unite at each period (Mean and SD in ISQ value)

Implant	Fixture installation	12weeks	RFA gain
H2-R8.5	75.0 ± 3.4	73.2 ± 4.7	-1.8 ± 5.7
Ti-Unite MK4	68.7 ± 8.1	72.6 ± 3.9	3.9 ± 8.1

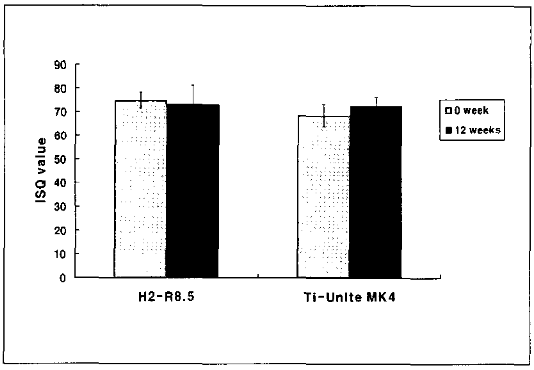

Fig. 1. RFA at implant placement and after 12 weeks.

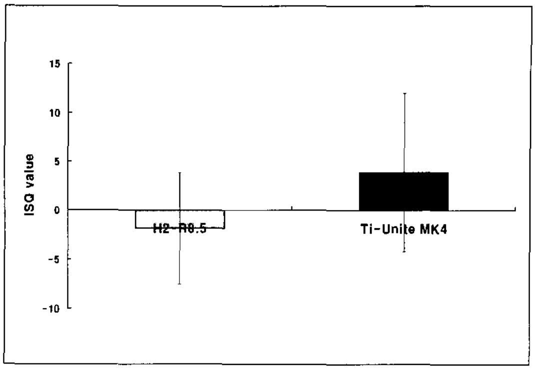

Fig. 2. RFA change after 12 weeks.

($P>0.05$) (Fig. 1) From the data, RFA gains after 3 months were calculated, and there was statistically significant difference between groups. ($P<0.05$) (Fig. 2)

DISCUSSION

To determine the ability of the surface properties of oxidized implants to influence bone response, the bone response was measured with the RFA value.

Rough surface implant showed great success rate clinically, and took the place of prototype implant - machined implant. Many surface treating techniques were developed, and being developed now - sand blasting, acid etching, ion deposition, anodic oxidation etc.

In this study, among the above surface modifications, we focused on anodic oxidation technique. Ti-Unite (Nobel biocare) implant is produced under static current method. In this case, voltage is changing continuously, generally growing up as surface oxide getting thicker. We used static voltage technique at 300 voltage, and some fluctuation was used for thicker oxide layer.

Implant primary stability is not only depends on bony quality and quantity but also depend on surgical technique used.[11] Bony housing used in this experiment was tibia of rabbit, therefore the physical properties of implant bed were similar condition. Surgical protocols of implant insertion and implant macrostructure provide a mechanical engagement and hoop stress on bone-implant interface and these make primary stability of implant. We set up different stability condition from the start according to manufacture' s guide. After 12 weeks, there were no significant differences in RFA values between groups, but slight tendency of high level ISQ of H2-R8.5 test groups were expressed.

Test groups showed drop of ISQ after 12 weeks. After 3 months, all implants had enough stability in terms of secondary stability. During 12 weeks, there was remodeling of bone. According to the difference of magnitude of hoop stress, the phase of bone response might be different. It was expressed by ISQ change between groups. At clinical immediate loading condition, which type of primary stability will benefit and guarantee bony remodeling and conversion to secondary biologic stability is in question. May be extra ISQ values guide and protect from environmental force.

In summary, the results of the present study indicated that all anodized implant surfaces are compatible to the biologic action of bone and above critical level of implant stability, increase or decrease of ISQ value according to conversion from primary stability to secondary stability might be have little significance in implant survival.

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. There were no statistically significant differences between groups in RFA values after 12 weeks (P>0.05).
2. The RFA gains after 12 weeks were statistically significant difference between groups (P< 0.05). In H2-R8.5 group, there was drop of RFA value and in Ti-Unite MK4 group, there was increase of RFA value.

REFERENCES

1. Albrektsson T, Branemark PI, Hansson HA, Kasemo B, Larsson K. The interface zone of inorganic implant in vivo ; Titanium implants in bone. Ann Biomed Eng 1983;11:1-27.
2. Kasemo B, Lausmaa J. Aspect of surface physics on titanium implants. Swed Dent J 1983;28(Suppl.):19-36.
3. Zitter H, Plenk HJ. The electrochemical behavior of metallic implant materials as indicator of their biocompatibility. J Biomed Mater Res 1987;21:881-896.
4. Solar RJ, Pollack SR, Korostoff E. In vitro corrosion testing of titanium surgical implant alloys: an approach to understanding titanium release from implants. J Biomed Mater Res 1979;13:217-250.
5. Tengvall P, Lindstrom I. Physico-chemical considerations of titanium as a biomaterial. Clin Mater 1992;9:115-134.
6. Ishizawa H, Ogino M. Formation and characterization of anodic titanium oxide films containing Ca and P. J Biomed Mater Res 1995;29:65-72.
7. Sul YT, Johansson CB, Jeong YS, Albrektsson T. The electrochemical oxide growth behavior on titanium in acid and alkaline electrolytes. Med Eng and Phys 2001;23:329-46.
8. Meredith N. Assessment of implant stability as a pognotic determinant. Int J Prosthodont 1998;11:491-501.
9. Sennerby L, Meredith N. Resonance Frequency Analysis : Measuring implant stability and osseointegration. Compendium 1998;19:493-502.
10. Park C. A study of the measurement of the implant stability using resonance frequency analysis. PhD thesis, 2000, Dankook University, Korea.
11. Albrektsson, T., Branemark, P.I., Hansson, H., & Lindstrom, J. (1981) Osseointegratd titanium implants. Requirements for ensuring a long-lasting direct bone-to-implant anchorage in man. Acta Orthopaedica Scandinavica, 52, 155.

Reprint request to:
Seong-Joo Heo, D.D.S., Ph.D.
Dept. of Prosthodontics. College of Dentistry
Seoul National University
28-1 Yeongun-Dong, Chongno-Gu. 110-749, Seoul Korea
heosj@plaza.snu.ac.kr