Estimation of implant osseointegration and abutment screw loosening by resonance frequency analysis

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Background and Aim

Following the placement of an oral implant, primary mechanical stability is gradually replaced by biological stability. Primary stability is the mechanical engagement of an implant with the surrounding bone, whereas bone regeneration and remodeling phenomena create the secondary (biological) stability of the implant (Fig.1)^{1,2}.

It is of clinical relevance to know the development of osseointegration after installation to determine the appropriate loading time, as well as to detect the incidence of screw loosening after the implant's superstructure is mounted.

The aim of this study was to examine the progress of implant osseointegration and screw loosening by means of a resonance frequency analysis (RFA) in the rabbit tibia.

Fig. 1. Change of osseointegration over time

Methods and Materials

Evaluation methods

Resonance Frequency analysis (RFA)

- To evaluate osseointegration and screw loosening.
- A small 3D accelerometer was mounted and screwed on to the implant. Flexural vibration was directly applied to the abutment (Fig.2a).
- Two RF values of x- and y-axis direction (RFx and RFy) were used for evaluation. Z-axis excluded (Fig.2b).

Fig. 2. Resonance Frequency analysis System (a) and definition of axis in the analysis (b) (3 Channel, Input Range 500mV, Sampling Frequency20k/s, Time scale200:1)

Osstell ISQ®

- To evaluate osseointegration.
- Implant Stability Quotient (ISQ) value was used for evaluation.
- Smart Peg: Type 1 (Model exp.), Type 21(Animal exp.)

Periotest®

- To evaluate screw loosening.
- Periotest (PT) value was used for evaluation.

Statistical analysis

One-way analysis of variance (ANOVA) followed with Tukey HSD test for difference among 3 models and 3 cavities, and with Dunnet-test for screw loosening from initial value.

Model Experiment

Different hardness models

- Titanium implants (φ3.8 mm, 12mm, Setio®, GC) were placed into 3 different hardness mandibular models (Model_H (Hard), _M (Midium), _S (Soft)) (Fig.3).

Different size of implant cavities

- 3.1mm, 3.25mm and 3.4mm cavities (_S, _M, _L) were prepared in Model_H.
- Titanium implants (φ3.8 mm, 10mm, Setio®, GC) were placed into each hole.

RF and ISQ values were measured in each model.

Screw loosening

- Thirteen different screw loosening conditions were set up. Abutment screw tightened with 10N torque (starting point, 0 degree) and the screw was loosened by 5 degrees from 0 to 30 degrees, 10 degrees from 30 to 90 for measurement.

RF and PT values were measured in each condition.

Fig. 3. Model_H and Implant (Setio®, GC)

Animal Experiment

Approved by the Institutional Animal Care and Use Committee of the Tohoku University Environmental & safety Committee (2016DnA-021) . Carried out in the Institute for Animal Experimentation at Tohoku University Graduate School of Medicine.

Fig. 4. Schedule of the animal experiment

- One mature male New Zealand White Rabbit (16weeks).
- Three titanium implants (φ3.8, 6.5mm, Genesis®Plus, GC) were installed in both tibiae (n=6) (Fig.5).

Osseointegration

RF and ISQ values were measured 13 times including immediately after implant placement (Fig.4).

Screw loosening

- Abutment screw tightened with 10N torque (starting point, 0 degree) and the screw loosened by 5 degrees from 0 to 90 degrees.
- After 8 weeks, RF values of 13 different screw loosening conditions were recorded.

Fig. 5. Implantation in left tibia of rabbit and implant (Genesis®Plus, GC)

Results

Model Experiment

Different hardness models

Fig. 6. Comparison of RF and ISQ values in 3 different hardness models

Different size of implant cavities

Fig. 7. Comparison of RF and ISQ values in 3 different cavity's size

Screw loosening

Fig. 8. RF values of x-axis (a) and y-axis (b) with screw loosening

Fig. 9. PT values of x-axis (a) and y-axis (b) with screw loosening

Animal Experiment

Osseointegration

Fig. 10. Change in RF values with time in left tibia. Proximal side (a) middle (b) and distal side (c)

In the RF, no consistent tendency was observed among six implants in both directions (Fig.10). Except for L3 and R3 (not shown), ISQ values tend to decrease until 7 to 10 days after installation, i.e. dip, and gradually increased. ISQ values at day 7 and 10 were significantly lower than at other time points except for R3 and L3 which located in the distal side of tibiae (Fig.11).

Screw loosening

Fig. 12. RF values of x-axis (a) and y-axis (b) with screw loosening

In both RF and ISQ, Model_H was significantly higher than other two models in both directions (p<0.01) (Fig.6).

In the buccal-lingual side of RFx and ISQ, Cavity_S showed significantly higher values than implants with large cavity diameter. On the other hand, no significant differences were observed in the RFy and ISQ in the mesio-distal direction (Fig.7).

The RF values decreased in accordance with the rotation angle of screw increased. In the x- and y-axis vibration, RFy were found to be significantly different from the initial value at 10 and 15 degrees, respectively (Fig.8).

The PT values increased in accordance with the rotation angle of screw increased. X- and y-axis vibration were found to be significantly different from the initial value at 20 and 15 degrees, respectively (Fig.9).

Conclusions

- It was confirmed that the RFA of this study can evaluate the difference in hardness of the bone around the implant and the degree of initial fixation in the model experiment.
- Although RFA has not reached to evaluate the extent and the degree of osseointegration, it was possible to detect screw loosening in model and animal experiments.

In summary, the results suggest that although this RFA method have not been enough to detect the progress of osseointegration, it can be used for the detection of the screw loosening.

References

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