Effects of Varied Cortical shells and Tooth Situations to the Structure Resonance in Dental Implantation

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1 Background

The osseointegration assessment is an important requirement for clinical dentists and researchers [1]. Resonance frequency analysis (RFA) has been introduced to measure and monitor the evolution of implant stability [2]. Recently, RFA method has been developed on both experimental devices and numerical analysis. Zhuang *et al.* [3, 4] proposed a non-contact vibro-acoustic method for the detection of the defect orientation surrounding a bone-implant interface; besides, a finite element analysis (FEA) was applied to compare with bone block experiments for singling out defect orientation. Moreover, using computerized tomography (CT) images of young adult mandibular, Hsieh *et al.* [5] investigated the change in resonance frequencies (RFs) when the dental-implanted bone structure appear closed defects, vertical and horizontal bone defects on 3D FEA. Furthermore, the first structure mode characterizes the osseointegration of varied bone blocks was verified by our developed detection device and confirmed by numerical simulation [6]. The signification of side cortical shell was asserted in RFA.

However, bone block simulation is many times smaller than mandible (or maxilla). The different results between experimental bone block (in-vitro) and in-vivo should be considered. In some cases, it is impossible to detect first mode or the first mode is small signification for osseointegration assessment. The high mode, which is a visible peak on obtained RFs spectra, should be picked up and studied for evaluation implantation quality. On the other hand, structure dynamic depends on basic factors which are mode shape, stiffness, mass and damping ratio. Therefore, investigation in-vivo model with varied interface-tissue properties shall give us general understanding about the development of implant stability in RFA; besides, the effect of jawbone structure (implant position, side cortical shell and original teeth) to RFs will be studied. In vibration structure, a resonance frequency (RF), which have mode shape vector's direction same as impulse loading direction and the largest deformation of mode shape at measure point, is corresponded with a high amplitude of the peak in RFs spectrum. This RF has defined a detection mode (DM) which shall be studied to assess interface-tissue. These in-vivo simulation results showed that the first mode illuminates for global structure and the DM explains for local structure (surround implantation). It explains the small change of the first mode and the big change of DM with varied interface-tissue's properties. The DM is small different RFs among varied implantation position, but it is a divergence between the model with natural teeth and model without natural teeth beside implant location. Consequently, the DM shall be able to obtain from experimental spectra and significant for osseointegration assessment. This clarification can be use to correct in-vitro experimental set-up closer in-vivo if the DM is a research object in bone block. The obtained RFs strand is largely affected by local structure surrounding implant (side cortical shell, side natural teeth) and is little varied by implantation location on the jawbone.

2 Methods

The numerical in-vivo simulation was built up by mandibular CT images of a young adult [5]. The 3D FEA model of mandible included cancellous bone, cortical bone, implant-tissue interface, implant and magnetic pole, as shown in Fig. 1, 2. The cortical shell thickness is 1.8 to 2.2 mm. The implant with thread screw, which is simulated in real dimension, located at molar, canine and incisor position.

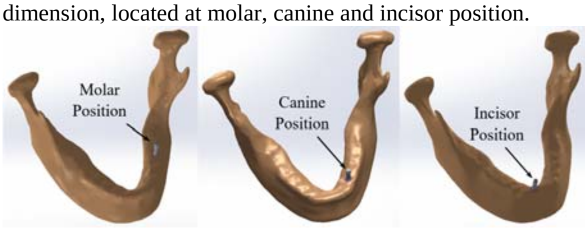

Fig. 1: FEA modeling of in-vivo mandibles with varied implant positions and with no natural teeth.

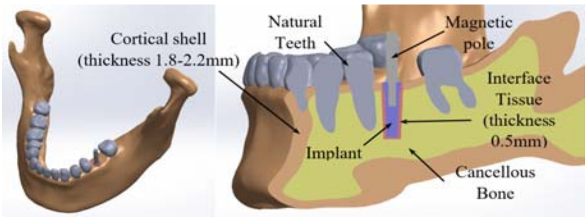

Fig. 2: FEA modeling of in-vivo mandibles with natural teeth.

The implant-tissue interface with thickness 0.5mm surrounding dental implant was assigned the elastic modulus 2 to 137 MPa and the density 50 to 320 Kg/m^3 to simulate the development of osseointegration from beginning primary stability to complete healing phase. In this situation, the complete healing phase is considered close to the cancellous bone. The magnetic pole was modeled without thread screw. The perfect bonding was applied for contact between cancellous and cortical bone, cancellous bone and interface tissue, cortical bone and interface tissue, implant and magnetic pole, teeth and jawbone. The contact between implant and interface tissue, which is friction, is assigned 0.7 for friction coefficient. The FEA model contained hexahedral solid elements and tetrahedral solid elements. The material of in-vivo model was assumed homogeneous, isotropic and linear elastic. The material properties of in-vivo simulation were indicated at Table 1. The in-vivo model was computed in modal analysis and undamped harmonic response with 80 design points which were selected from interface tissue material property range (young modulus: 2-137 MPa; density: 50-320 Kg/m^3). The RFs and corresponding mode shape were computed using ANSYS 13 (ANSYS®, Inc., USA).

Table 1 Material property of FEA modeling [5, 7]

	Young's modulus (MPa)	Density (kg/m^3)	Poisson's Ratio
Ti (implant)	113,800	4,480	0.34
Al (peg)	70,500	2,780	0.35
Cortical bone	16,000	1,640	0.26
Cancellous bone	23	160	0.3
Teeth Dentine	24400	1600	0.43
Interface-Tissue	2 - 137	50 - 320	0.22

3 Results

The first mode shape and DM shape of mandibular simulation were illustrated in Fig. 3. All free parts of the mandibular structure were deformed in the first mode shape, but the DM shape is only big deformation at the magnetic pole, implant and surrounding implant whereas other parts were very small deformation similar to the rigid body. The surface was figured out in Fig. 4 which illustrated a small change in RFs of the first mode along varied interface tissue young's modulus and density values. However, the big improvement indicated in RFs of DM with increasing interface tissue's modulus. The predictable RFs of DM trends with varied interface tissue young's modulus were increased logarithmic function in Fig. 6. The mandible without teeth model showed that RFs range from 1121 to 1125Hz in the first mode and from 2152 to 6570Hz in the DM mode, but RFs is a higher range from 3153 to 8050Hz in DM mode with jawbone simulation including teeth.

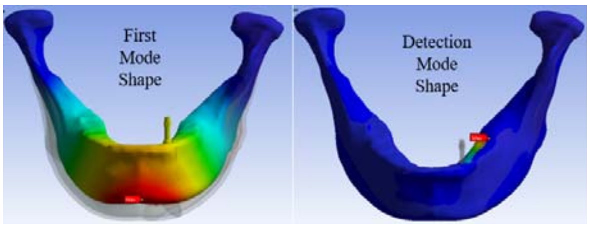

Fig. 3: Mandibular FEA mode shapes.

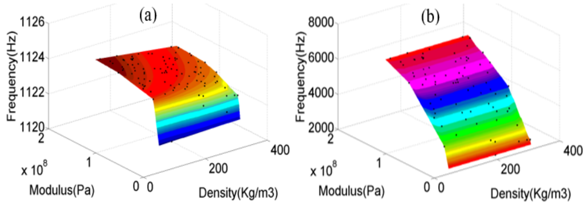

Fig. 4: RFs surface of first mode (4a), RFs surface of DM mode (4b) in Mandibular FEA without teeth.

4 Interpretation

The first mode is known as a standard mode to evaluate the change in stiffness dynamic structure, but it is difficult to obtain and small significance with evolution interface-tissue (Fig. 4a, 5). Therefore, the DM has defined a vibration mode which is able to detect from RFs spectrum (Fig. 4b, 5). The DM increase with raising interface tissue young's modulus and is little decreased by mass. Local structure surround implant (side cortical shell, teeth) is the main reason for the change in RFs of DM (Fig. 6b). Otherwise, numerical RFA results do not depend on implantation location, shown as Fig. 6a. The significance of using DM is worthy to assess osseointegration in-vivo and side cortical shell, natural teeth should be considered in RFA study.

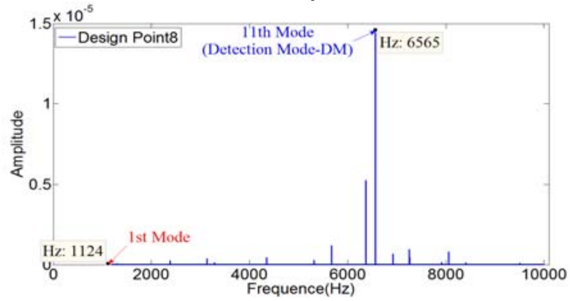

Fig. 5: Obtained RFs from Mandible FEA without teeth (Interface-tissue modulus: 136.2 MPa, Density: 299.2 Kg/m^3)

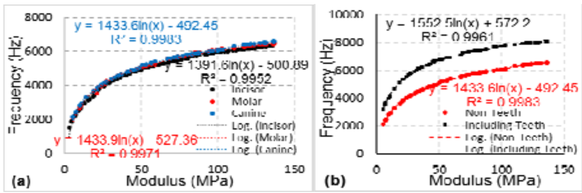

Fig. 6: Comparison RFs trends between Incisor, Canine and Molar position (a), Mandible with and without teeth (b).

Acknowledgement

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