Clinical Biomechanics 48 (2017) 110–117

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Immediate mechanical stability of threaded and porous implant systems

Do-Gyoon Kim[a,*], Yong-Hoon Jeong[a], Hua-Hong Chien[b], Amanda M. Agnew[c], Jin Whan Lee[d], Hai Bo Wen[d]

[a] Division of Orthodontics, College of Dentistry, The Ohio State University, Columbus, OH 43210, USA
[b] Division of Periodontology, College of Dentistry, The Ohio State University, Columbus, OH 43210, USA
[c] Injury Biomechanics Research Center, College of Medicine, The Ohio State University, Columbus, OH 43210, USA
[d] Dental Research and Clinical Affairs, Zimmer Biomet – Dental Division, Palm Beach Gardens, FL 33410, USA

ARTICLE INFO

Keywords:
Primary stability
Thread implant
Porous implant
Resonance frequency analysis
Dynamic mechanical analysis

ABSTRACT

Background: Primary stability of a dental implant system is an essential factor to maintain its long-term success. Thus, the objective of this study was to examine whether primary stability is different between threaded and porous dental implant systems placed in artificial bone blocks and human cadaveric mandibular bone.

Materials and methods: Forty-two threaded and 42 highly porous dental implants were placed in artificial polyurethane bone foams with 7 different thicknesses (3.5 to 12 mm). In addition, 11 threaded and 11 porous implants were installed in 8 edentulous mandibles of human cadavers. Implant stability quotient values, insertion torque, static and dynamic stiffness, and viscoelastic tan δ of each implant system were measured. Mean gray values were obtained at the implantation sites in the human mandible.

Findings: The porous implant group had substantially lower implant stability quotient values and insertion torque values than the threaded implant group that were equal or > 5.5 mm in thickness of the artificial bone block ($p < 0.026$) with the exception of 8.5 mm thickness, while static and dynamic stiffness values were not different between the two implant groups greater than 5.5 mm in thickness ($p > 0.132$). Static and dynamic stiffness values of the porous group were significantly greater than the thread group in the human mandibular bone ($p < 0.015$).

Interpretation: The porous layer supports axial loading better than lateral and shear loading of the dental implant system. This result indicates that trabecular shaped architecture of the porous layer may provide sufficient anchorage compromising reduction of the axial primary stability of the porous implant system to be comparable with the threaded implant system.

1. Introduction

Strong primary stability of a dental implant in oral bone is an essential factor to maintain success of the whole dental implant system (Bencharit et al., 2014; Sennerby et al., 2015). It has been suggested that excessive micromotion between bone and the implant surface reduces primary stability and produces fibrous tissue at the interface leading to failure of the implant system (Brunski, 1999; Sennerby et al., 2015; Turkyilmaz et al., 2008). Factors that can influence primary stability include the quantity and quality of bone surrounding the implant, surgical technique and implant design (Javed and Romanos, 2010). In addition to other factors, dental implants can be designed to improve their primary stability in oral bone. Two major traditional dental implant designs that have been popularly used are threaded and porous shapes. As the implant threads provide theoretically tighter interlock than the porous shape to surrounding bone at the placement of implant, the threaded dental implant is often assumed to provide better primary stability. However, a lack of prior research warrants a direct comparison between these implant shapes to determine their primary stability.

Dental implant system stability has been experimentally assessed in laboratories using push-out fracture and fatigue mechanical testing (Romanos et al., 2014; Seong et al., 2013; Standardization IOf, 2016; Toyoshima et al., 2015). However, such destructive testing is not feasible in a clinical model. Alternatively, resonance frequency analysis (RFA) was introduced as a non-invasive and highly reproducible method to estimate the stability of dental implants in patients (Aparicio et al., 2006; Ersanli et al., 2005; Meredith et al., 1996). RFA is a non-contact method that uses a sine wave with different frequencies to obtain amplified resonance frequency signals reflecting from a transducer installed in the top of implant (Meredith et al., 1996; Sennerby and Meredith, 2008). While it was not clearly understood which

* Corresponding author at: Division of Orthodontics, College of Dentistry, The Ohio State University, 4088 Postle Hall, 305 W. 12th Ave, Columbus, OH 43210, USA.
E-mail address: kim.2508@osu.edu (D.-G. Kim).

http://dx.doi.org/10.1016/j.clinbiomech.2017.08.001
Received 28 July 2016; Accepted 4 August 2017

mechanical properties the RFA can account for, a recent study demonstrated that implant stability quotient (ISQ) values provided by the RFA had strong correlations with insertion torque, static and dynamic stiffness, and viscoelastic energy dissipation ability (tan δ) of threaded dental implants placed in various artificial bone thicknesses (Kim et al., 2015). The dynamic stiffness and tan δ were measured by dynamic mechanical analysis (DMA) that uses low level oscillatory loading at different frequencies to characterize static, dynamic, and viscoelastic behavior of a material (Amorosa et al., 2013; Menard, 1999; Stroede et al., 2012). Thus, both DMA and RFA could provide similar mechanical testing conditions.

In the current study, we hypothesized that the properties of primary stability, including the ISQ value, insertion torque, static and dynamic stiffness, and viscoelastic energy dissipation ability (tan δ), will be different between threaded and porous implant systems. This hypothesis was addressed by comparing the properties between a traditional threaded dental implant and a hybrid dental implant system consisting of threaded and porous sections. Thus, the objective of the current study was to examine whether primary stability is different between the threaded and porous dental implants placed in artificial bone blocks and human cadaveric mandibular bone. For comparative purpose, all data of the threaded dental implants were obtained from the previous study (Kim et al., 2015) that used the same experimental protocol as the current study, but without the porous dental implants.

2. Methods

2.1. Dental implants

Two dental implant groups were compared. One group was a threaded dental implant (Tapered Screw-Vent® Implant, 4.1 mm diameter × 10 mm length, Zimmer Biomet, Palm Beach Gardens, FL) and the other group was a porous dental implant (Trabecular Metal™ Dental Implant, 4.1 mm diameter × 10 mm length, Zimmer Biomet) (Fig. 1). The threaded part of both implants was composed of titanium alloy (Ti6Al4V). The crestal region had a 0.5 mm machined collar and a 1.8 mm section of textured microgrooves measuring 0.1 mm in depth. The porous implant was a 3-piece welded construction that included a (1) microgrooved cervical section above 1.9 mm of threads, (2) unthreaded midsection of highly porous tantalum material, and (3) threaded apical section. The titanium alloy thread surfaces of both implants were microtextured by grit-blasting with hydroxyapatite followed by a non-etching hydrochloric acid wash to remove the blasting media (MTX® Microtextured Surface, Zimmer Biomet).

2.2. Implantation in artificial bone blocks

Although the exact same experimental protocol as used for the threaded dental implants in the previous study (Kim et al., 2015) was used, we described the current experimental protocol for both the threaded and porous dental implant groups. Seven different thicknesses (3.5, 4.5, 5.5, 6.5, 7.5, 8.5, and 12 mm) of solid, rigid polyurethane (PU) foam sheets (density: 0.8 g/cm^3, Sawbones, Vashon Island, WA) (artificial bone) were obtained. Each sheet was cored to make 12 artificial bone blocks with 20 mm diameter (Fig. 1). A total of 84 artificial bone blocks were utilized by assigning 42 (6 blocks for each thickness) for each implant group.

A pilot hole (1 mm diameter) was drilled at the center of each bone block through its thickness, which could provide a consistent straight guide line for accurate implantation. The artificial bone block was placed in a custom jig that was fabricated to obtain a plane strain boundary condition of oral bone (Fig. 2a). The holding screws of the jig were adjusted to accommodate the various thicknesses of the artificial bone blocks. With the 1 mm-diameter prepared hole as a guide, spade drills in graduated diameters were sequentially used to prepare receptor sites in the jig-mounted bone blocks. The threaded and porous dental implants were placed in the prepared receptor sites according to the manufacturer's instructions for use.

2.3. Implantation in human cadaveric mandibles

Eight edentulous mandibles were obtained from human cadavers (4 males and 4 females aged 48 to 101 years) provided by the Body Donation Program at The Ohio State University. No records of bone disease or gross evidence of it were observed on the specimens. These cadaveric mandibles were not fixed with any chemicals. After soft tissues were removed, the mandibular bones were stored in a freezer at − 21 °C.

The human mandibles were scanned by a cone beam computed tomography (CBCT) scanner (iCAT, Imaging Science International, Hatfield, PA, USA) at 200 μm voxel sizes under the scanning energy of 120 kV and 5 mA, which is the scanning range used in a clinical setting (Fig. 3b). After scanning, for 7 mandibles, 4 dental implants were placed on contralateral sides of each mandible to make a pair of the two implant groups (Fig. 3a,c). For the 8th mandible, a contralateral pair of 1 threaded and 1 porous implants were used. The mandibular side to install the first implant was randomly chosen. Implantation in the mandible was conducted following the usual surgical process under irrigation. The implantation site in the 3D CBCT image was identified by referring to the post-implantation picture and CBCT image (Fig. 3a,c). The volume of interest was same for each site with Ø4.5 × 10 mm regarding the dimension of implants. Then, mean gray values were computed by dividing the sum of gray values (CT attenuation coefficients) by the total number of bone voxels at the implantation site, which is proportional to bone mineral density.

2.4. Insertion torque and implant stability quotient (ISQ) values

All measurements were conducted immediately after implantation in the jig-mounted artificial bone blocks. The jig holds the artificial bone blocks under the same residual strain condition using uniform compression from the upper piece of holder fixed by six screws. This

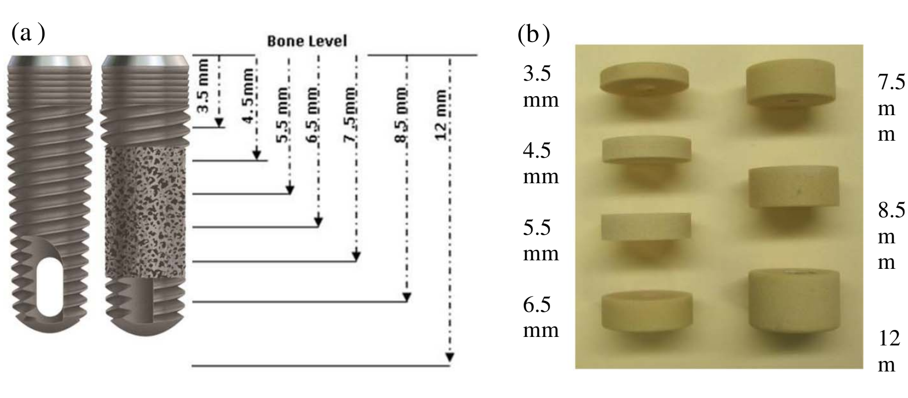

Fig. 1. Bone level for the threaded and porous dental implant systems in the artificial bone blocks. (a) A dental implant with different implantation depths and (b) different thickness of bone blocks.