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Materials Science and Engineering C 26 (2006) 1307 – 1311

MATERIALS SCIENCE & ENGINEERING C

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Effect of bone density on the damping behavior of dental implants: An in vitro method

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Abstract

For normal healthy teeth the percussive energy generated by mastication is attenuated by the periodontal ligament at the healthy bone–natural tooth interface. However when the natural tooth must be replaced by an implant due to damage or disease the ligament is lost and the implant will transmit the percussive forces directly into the bone. Studies have been carried out to examine the mechanical damping behavior of dental implants. However, a study of the effect of bone density at the time of implant placement in conjunction with quantitative measures of mechanical energy dissipation has not been reported. The present research hopes to uncover some of this missing information by evaluating the effect of bone density on the energy dissipation of an implant upon surgical placement. In this work, four different dental implant geometries were tested as a function of simulated bone density utilizing a series of artificial foam bone models (Pacific Research Laboratories, Vashon Island, WA) that vary in density and structure. The implants were placed following recommended placement protocols. The hypothesis of the work is that the Periometer, a percussion probe system designed to measure local damping capacity, can be used to assess the quality of the underlying support structure. It is also hypothesized that Periometer results can be used to differentiate between implant model geometries within the same support structures.

Keywords: Osseointegration; Loss coefficient; Dental implants; Bone density

1. Introduction

Immediate loading in dental implants is a treatment method in which an implant is placed in the jaw, and an abutment is attached above it so that the percussive forces of chewing are transmitted to the bone and the site is mechanically loaded from the time of implant placement. Alternately, implants can be placed and then covered to allow for bone healing and osseointegration before being uncovered and connected with an abutment to facilitate mechanical loading [1].

Bone requires an amount of loading sufficient to strengthen it by inducing bone formation and remodeling along the wound site. If this threshold level is not met or is greatly exceeded the bone will begin to undergo osteoclastic activity and be removed from the site [2,3]. Therapeutic loading for a dental implant needs to meet the threshold of the required force transmission of natural teeth which have a kinetic energy loss coefficient of around 0.10. This natural level of force transmission is controlled by the periodontal ligament which surrounds the natural tooth [4]. Since this or any other natural cushioning ligament is lost with the placement of a prosthetic, it is very important that the implant be designed to transmit near natural level stress waves through the tissue. It is also important that the tissue be sufficiently stable so that the implant is securely held in place before loading occurs.

The Periometer is a percussion probe instrument that we hypothesize is capable of distinguishing the quality of the underlying bone at the time of placement. The Periometer operates by actuating a rod to impact the sample 16 times over a four second time span. Software developed using the LabView environment records data from 10 of these percussions and registers it as a truncated graph of energy vs. the time of each impact. This is the raw energy return and is used to determine the loss coefficient as described previously [5]. The Periometer delivers a maximum force approximately equal to 10 N to the abutment, which is about the same as

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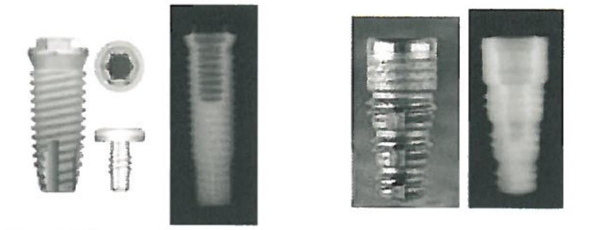
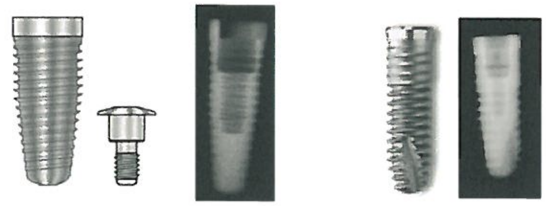
doi:10.1016/j.msec.2005.08.019

that delivered by the Periotest instrument [6]. This loading amplitude is considerably less than that typically measured for normal occlusion [7]. We hypothesize that the Periometer will be able to distinguish the differences in primary stability of dental implants in several different densities of an artificial bone model material.



Nobel Biocare Branemark System MK IV

Friadent Frialit -2 Synchro



Nobel Biocare Replace Select Tapered

Friadent XiVE

Fig. 2. The different geometries of the four implants used in the study can be clearly seen in the catalog images from their respective producers and our X-rays of the implants.

2. Materials and methods

Solid rigid (closed cell) polyurethane blocks and cellular rigid (open cell) polyurethane blocks of foam 13 × 18 × 4 cm (Pacific Research Laboratories, Vashon Island, WA) were selected in densities measured at 120, 160, 200, and 320 kg/m^3 (7.5, 10, 12.5, and 20 lb$_m$/ft^3) for the open cell foams, and 160, 240, 320, and 641 kg/m^3 (10, 15, 20 and 40 lb$_m$/ft^3) for the closed cell foams to model the cancellous bone normally found at implant sites. The blocks were cut into smaller blocks measuring 2.5 × 2.5 × 4 cm, Fig. 1. Friadent Frialit®-2 Synchro, and XiVE® dental implants (Dentsply Friadent CeraMed, Lakewood, CO) and Nobel Biocare Brånemark System® MK IV, and Replace® Select Tapered (Nobel Biocare, Yorba Linda, CA) implants were placed in the center of the square face of each block per standard placement protocol by a representative of the respective company, Fig. 2. All of the implants were 1.3 cm in length. Each implant was placed in duplicate resulting in a complete set of 16 blocks (two of each of the 8 densities) for each implant model. Abutments specific to each type of implant were inserted and tightened to 20 N cm of torque in each block with a Brånemark System® Torquecontrol (Nobel Biocare, Yorba Linda, CA) adjustable torque driver. The Frialit-2 Gingiva Former ∅5.5 mm, GH5 mm, was used for the Friadent implants. The Nobel Biocare implants used Healing Abutment Bmk Syst RP ∅5 × 5 mm, and Healing Abutment Select RP ∅6 × 5 mm, respectively for the Brånemark and Select implants.

2.1. Dry tests

Implants were tested with the Periometer utilizing a specially designed PTFE tip which held the implant in a cup shaped slot to ensure good contact with all of the abutments as shown in Fig. 3. All blocks were marked at 2.54 cm from the bottom edge on opposite sides to ensure that they were placed level in the clamp. One of these two faces was arbitrarily marked to indicate that it was the front face and this side was positioned towards the Periometer tip. Blocks were centered in a clamp which was tightened to 2.56 cm total distance between the supports. Tests were done in triplicate and the average kinetic energy loss coefficients as well as the individual test values were recorded for each block density and implant type.

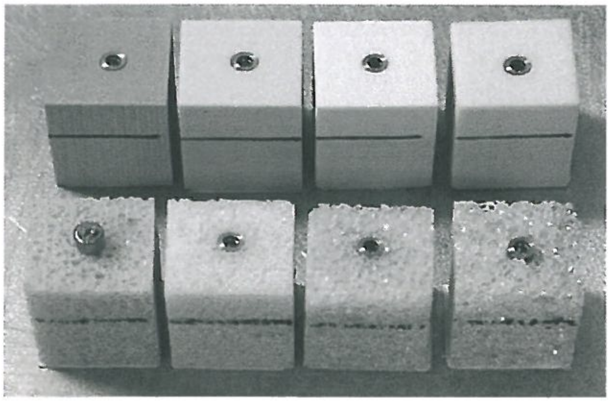


Fig. 1. The eight different blocks used in the experiment are shown, here with the open cellular rigid (open cell) blocks in the front and the solid rigid (closed cell) foams in the rear row.

2.2. Wet tests

In order to simulate the presence of plasma in cancellous bone a thin and well characterized latex barrier (Church and

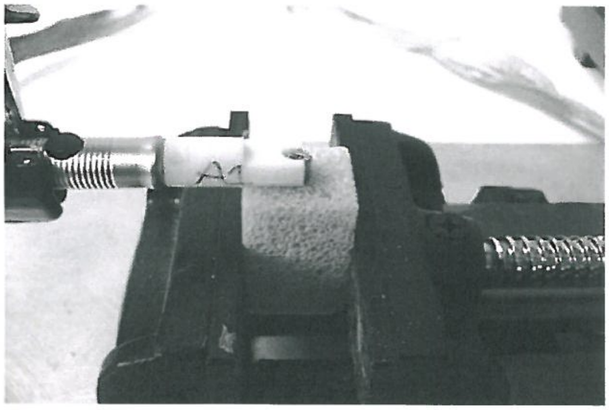


Fig. 3. The hand piece of the Periometer can be seen in contact with an abutment in this picture of the test setup.

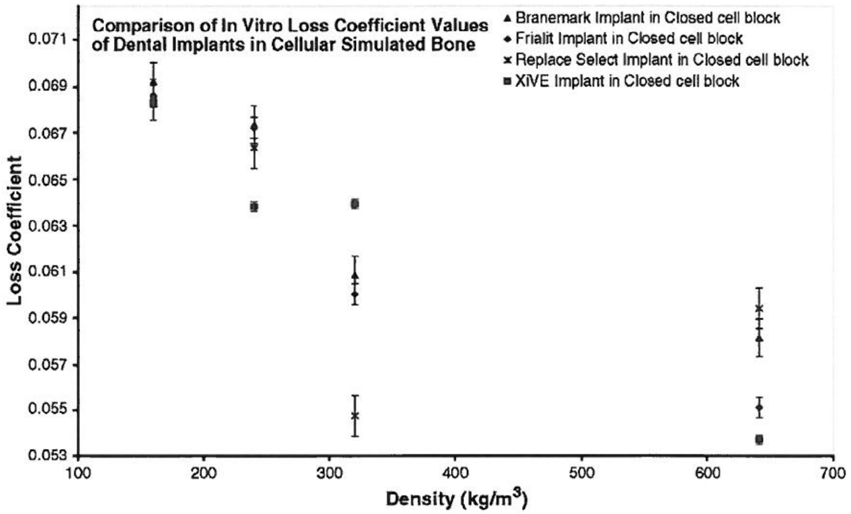


Fig. 4. The lower loss coefficients values of the denser foam blocks can be seen in this data from the solid rigid (closed cell) polyurethane foam blocks containing the two types of Friadent implants.

Dwight, Princeton, NJ) was used to hold the open cell blocks in contact with 1× phosphate buffered saline (PBS) during testing. The appropriate abutments were placed as described above. Blocks were placed in the barrier and surrounded by 15 ml of PBS before being placed in the clamp. Because of the nature of the barrier, the clamp could be tightened to the same distance used in the dry tests to hold the block steady. The system was such that a reservoir of liquid was located below the block and the bulk liquid did not rise above the level of the clamp on the foam except as retained liquid in the pores of the foam. Periometer measurements were taken in triplicate and the average loss coefficients as well as the individual test values were recorded for each block density and implant type.

3. Results

3.1. Dry tests

Measurements were obtained for all of the blocks in initial tests although in repeated testing some blocks came back as unmeasurable, specifically the Brånemark System implants in the cellular rigid (open cell) foams of density values 120 and 160 kg/m^3. Repeated testing also caused the readings from the Replace Select implants to be more difficult to obtain, the Frialit-2 and XiVE implants withstood repeating testing slightly longer. All of the implants loosened in the blocks with repeated testing and, if continued, would eventually become too loose for accurate data collection. All of the data reported here is from the first or second

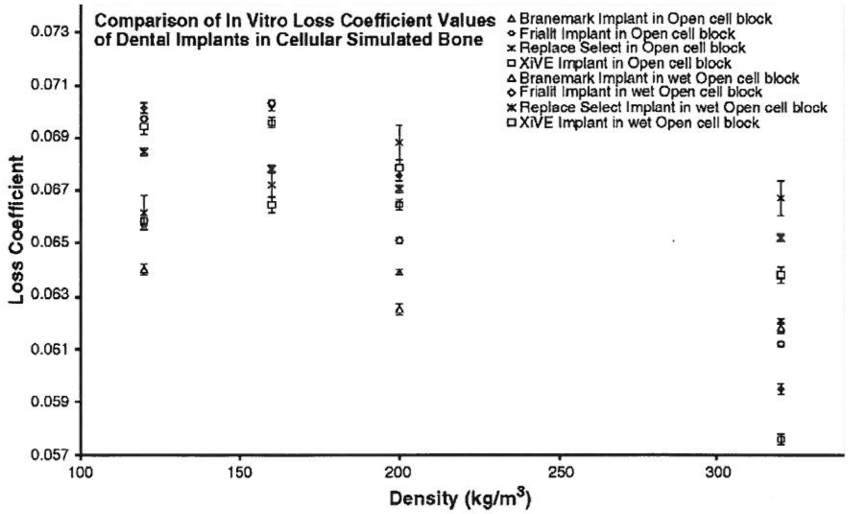


Fig. 5. The lower loss coefficients values of the denser foam blocks can be seen in this data from the cellular rigid (open cell) polyurethane foam blocks containing the two types of Nobel Biocare implants.

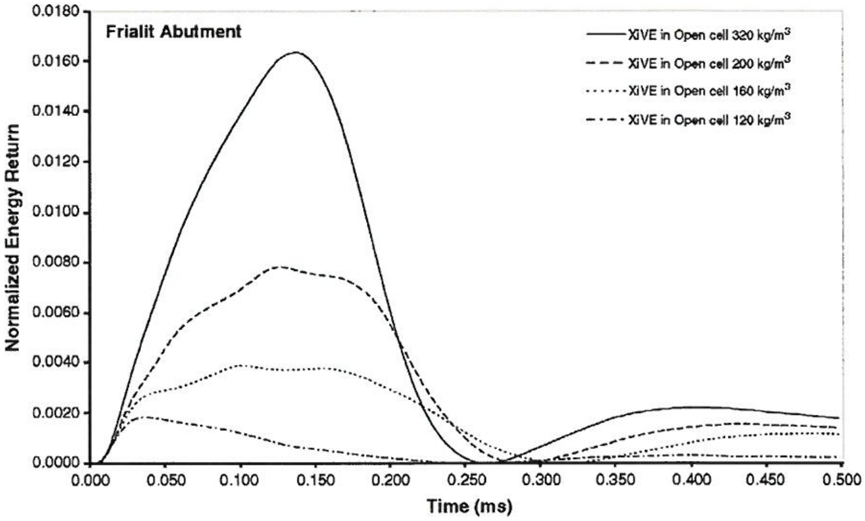


Fig. 6. The Periometer uses the energy return to calculate the loss coefficient. The raw data from the energy return can also be used to detect poor implant stability in the block as seen in this data from XiVE implants in rigid cellular polyurethane foams.

round of tests. It is important to note that the repeated testing for these in vitro implants was performed after the data were recorded for the present immediate loading study. Loosening as a result of Periometer testing would not be expected for in vivo testing due to the adhesion provided by the extra cellular matrix as well as the presence of a high density layer of cortical bone at the dorsal bone/implant interface.

In all of the four implant types and the two different block families the loss coefficients follow increasing trend as the density of the block decreases. This trend holds for both the open and closed cell foam blocks. The implants in closed cell blocks exhibited loss coefficients that were more tightly grouped at the lower densities than the implants in the open cell blocks as shown in Figs. 4 and 5. This is to be expected as closed cell foams have smaller, more uniform pore sizes while the open cell blocks contained larger pores with more variation in size. The energy return data suggests that the Periometer can be used to detect poor stability at the bone/implant interface as caused by defects or irregularities in the bone structure. This is evidenced by a variation from a uniform bell-shaped curve in Fig. 6 for the energy return versus time. While the shape of the energy return is specific to each block and density, lower density foams tend to have more fluctuations in the energy return curves, indicating that the implants are not held uniformly in contact with the substrate.

3.2. Wet simulated bone

The data from the tests performed while the blocks were held in PBS solution show the same trend of increasing loss

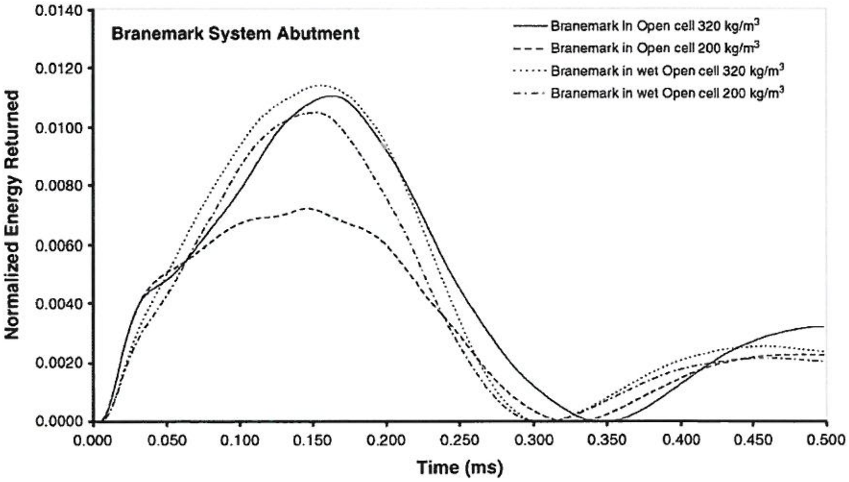


Fig. 7. Wetting the blocks seemed to help smooth out the shoulders on many energy return curves as seen in this plot of the energy return of a Brånemark Implant in a cellular rigid (open cell) block.

coefficient with decreasing density. Interestingly, the addition of the liquid to the system seems to in most cases ease the integration of the implant into the block and lessen the number of fluctuations in the energy return curves as shown in Fig. 7. This smoothing is also seen in the plots of the data from the Friadent brand implants, energy return plots for samples with multiple fluctuations when dry are much more uniform for wet conditions.

A statistical analysis (two way ANOVA, $p = 0.05$) of the loss coefficient data shows that implants placed in foams that are at least 80 kg/m^3 different in density regardless of cellular structure have significant differences in the measured loss coefficient value in both the Nobel Biocare and Friadent implants. The differences in the actual implant Nobel Biocare geometries seems to be more important when the implants are in the wet substrate, however the geometries do not have as much influence on the results for the Friadent implants in the present simulated bone model.

4. Conclusions

The Periometer percussion probe instrumentation provided both measurements of the loss coefficient and energy return–time curves that were used in the present study of the larger cellular nature of the cellular rigid foams. Although the loss coefficient generally does decrease with increasing bone density as expected, it was evident that the structure of the bone/implant interface also strongly affected this parameter. This finding is supported by the observation of greater fluctuations in the energy return for values of loss coefficient that were higher than expected based on the simulated bone density. In light of the present results, plans have been made to examine the use of the Periometer to track bone healing in vivo over the course of an induced injury and recovery period in an animal model.

Acknowledgements

The authors would like to thank Dentsply and Nobel Biocare for their support in providing the implants for the present work and with implant placement in the simulated bone models.

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