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Session 6 - Environmental Systems: Management and Optimisation
Session 7 - New Methods and Technologies for Medicine and Biology
Session 8 - Embedded System Design and Application
Session 9 - Image Processing, Image Analysis and Computer Vision
Session 10 - Mobile Communications
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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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Joerg Meyer / Raymund Espiritu / James Earthman

Virtual Bone Density Measurement for Dental Implants

MEASURING OSSEOINTEGRATION OF TITANIUM IMPLANTS

The term *osseointegration* describes the integration of a dental implant into the surrounding bone material. A method for virtual bone density measurement has been developed, which is based on digital image processing of CT scan data. In a cadaver study, a CT scan of the maxilla has been obtained, and two implant sites with somewhat complementary properties have been selected as objects of study.

The visualization procedure consists of 2-D cross-sectional CT imaging, 3-D gradient-based hardware-accelerated volume rendering using 3-D texture mapping, implant site extraction using 3-D selection of a 2-D cross-sectional, tri-linearly interpolated 2-D image, and computation of a bone density profile and line integral along the implant. By visually displaying the effects of variations in implant size, location of the implant site, bone density, and osseointegration, conclusions can be drawn for optimal placement and anchoring of dental implants, eventually leading to more stability, higher durability, and an increased lifetime of the implanted tooth.

Introduction

Virtual bone density measurement uses three-dimensional imagery from a CT scan of the specimen to determine X-ray absorption in tissues, which is directly correlated to bone density. In our method, an arbitrarily located two-dimensional cross-section is extracted from the 3-D scan, which represents an anatomical feature, in our case a dental implant. After choosing the location, a measurement is taken on the 2-D image. In the given study, the measurement is an indicator for the degree of osseointegration of a dental implant.

Background and Significance

For healthy teeth, the percussive energy produced by mastication processes is attenuated by the periodontal ligament at the bone-tooth interface. This ligament, however, is lost when the natural tooth is replaced with an implant for reasons such as disease or irreparable damage. The implant transmits the percussive forces directly into the bone at the material-bone interface.

In this study, two different dental implant sites (figure 1) were evaluated using a cross-sectional image based method for the computation of bone density as a function of distance from the implant apex. Each cross-section is centered on the longitudinal axis of the implant reaching from the buccal to the lingual side. A sequence of density values along one side of the implant is called a profile. The average of such a density profile represents a line integral, which is an indicator for the degree of osseointegration.

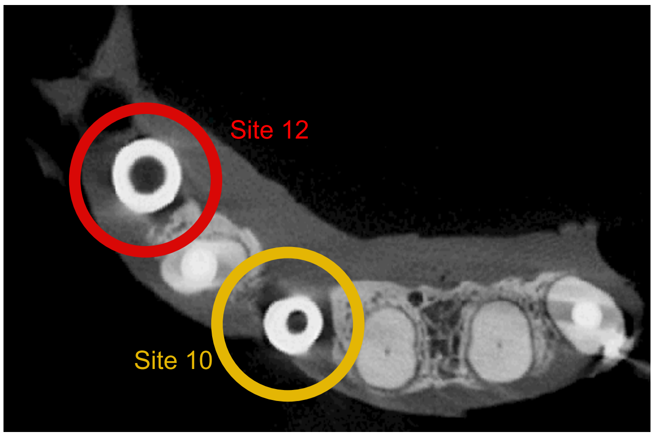

Fig. 1. Selected implant sites 10 and 12

Related Work

Osseointegration is the permanent incorporation of an implant into bone. This direct and functional connection cannot be separated without fracture. Osseointegration is an important process, along with bone healing, that occurs after dental implants are placed and covered, after which the implants are uncovered and connected to an abutment to allow for mechanical loading [1].

A sufficient amount of loading is needed to strengthen bone through bone formation around the wound site. If this requirement is not met or significantly exceeded, osteoclastic activity will commence and the bone subsequently removed from the site [2, 3]. In therapeutic loading for dental implants, the implant design must replace the function of the periodontal ligament that is lost upon prosthetic placement by transmitting stress waves through the tissue near the natural level [4]. Also, the surrounding bone tissue must be stable to secure the implant prior to loading.

Given the importance of monitoring the development of bone that provides support, this paper suggests a virtual method of profiling the bone density gradient that surrounds the implant.

The visualization methods include 2-D cross-sectional CT imaging, 3-D gradient-based [6], hardware-accelerated volume rendering using 3-D texture mapping [7, 8, 9], and implant site extraction using 3-D selection of a 2-D cross-sectional, tri-linearly interpolated 2-D image [10, 11].

2-D Measurement of Osseointegration

In order to measure bone density in the proximity of the implant site, a two-dimensional cross-section was extracted from the volumetric grid using tri-linear interpolation (figure 2). The cross-section intersects the longitudinal axis of the implant and reaches from the buccal to the lingual side. This way, a standardized coordinate system was defined for bone density measurements.

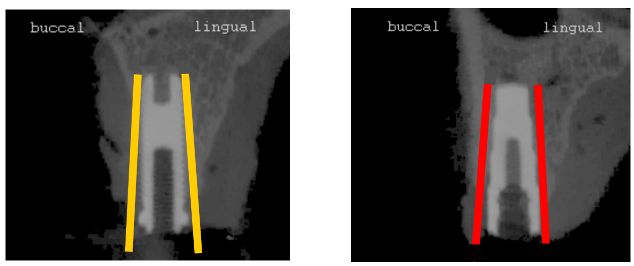

Fig. 2. Extracted cross-sectional image of implant sites 10 and 12 from 3-D scan

Using Bresenham's line algorithm, a straight line was drawn on both sides of the implants to collect density information near the implant. The line originates at the same vertical coordinate as the apex of the implant and maintains a predefined horizontal distance to the implant. This line was then used to collect the data for the bone density profile and to compute a line integral, i.e., a single number that is characteristic for the bone density of a particular implant and side (buccal or lingual).

In order to normalize the line integral and to make it independent of the size of the implant, only pixel values inside the bone and gums were included in the computation. Pixels with values characteristic for air (background pixels) were ignored. Also, if the line accidentally cut through the implant, those values would have been ignored as well. The sum of the pixel values was divided by the number of active pixels along the line in order to make the line integral independent from the size of the implant.

Typical profiles for implant sites 10 and 12 (buccal and lingual sides) are shown in figure 3. The horizontal axis represents the distance from the apex of the implant, and the vertical axis shows the intensity. The average, i.e. the value of the line integral, is shown as a horizontal line with a percentage value.

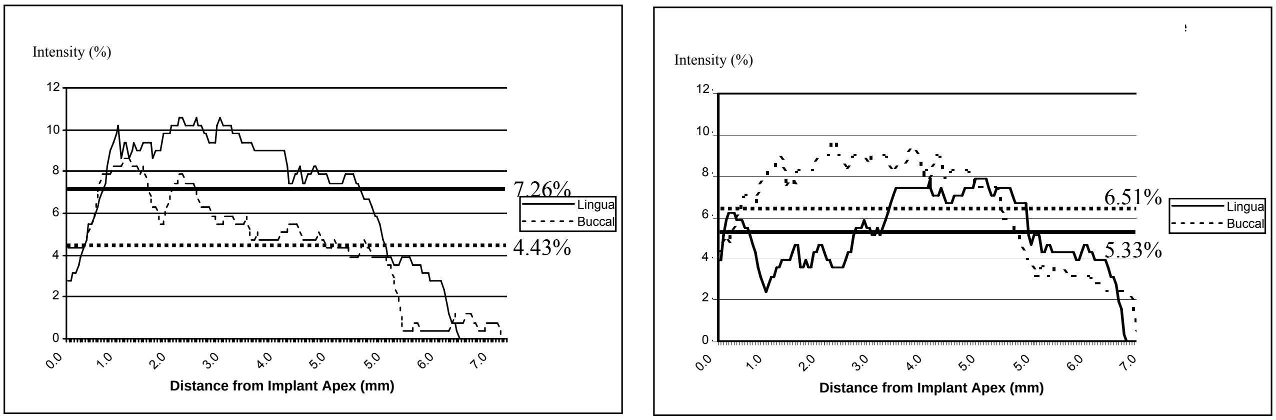

Fig. 3. Bone density (intensity) for the lingual and buccal sides of implant sites 10 and 12.

Please note that in implant site 10 the lingual side appears to be stronger, whereas in implant site 12 the buccal side appears to be stronger. This could have been caused by various effects, including aging, placement of the implant, and mechanical stress.

Visualization

Instead of presenting the data in a diagram, the density profiles can be visualized directly on the 2-D cross-section (figure 4). The orientation of the profiles has been rotated to reflect the mutual support of the implant from the bone on the buccal and lingual side.

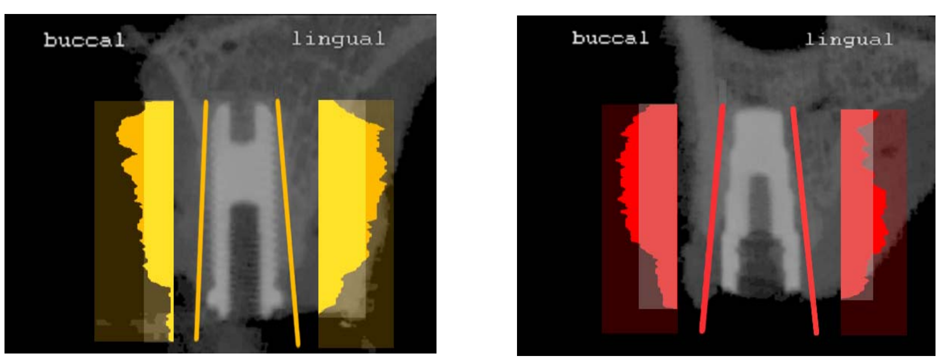

Fig. 4. Bone density profiles for the lingual and buccal sides of implant sites 10 (left) and 12 (right).

The width of the highlighted areas shows the value of the line integral as a single measure of osseointegration per site and per side (buccal or lingual). When shown in context, the profiles show the amount of horizontal support for each vertical position. The images clearly indicate that the support is usually better near the apex of the implant. The two examples also indicate that there may be differences in the buccal and lingual support of the implant.

Discussion of Results

The following observations were made from these visualizations. For both implant sites the bone density values followed a general trend of an initial rise, peak plateau, and fall as distance increased from implant apex (figure 4). Early rise and peak in bone density was generally seen within 3 mm from the implant apex. This range of increased bone density may be explained by the presence of a high-density layer of cortical bone at the dorsal bone/implant interface [4].

It is important to note the exception to this trend in the data collected for the lingual side of site 12 as shown in figure 4 (right). Another important observation to note is the lack of prominent plateaus in the curves generated for the buccal and lingual sides of implant site 10 as shown in figure 4 (left). These occurrences were validated with a mechanical study (percussion testing) that was conducted to verify the results from the virtual study [4].

Following the peak plateaus of bone density for both implant sites 10 and 12, which correspond to the lateral incisor, and 1st bicuspid or premolar, respectively, the buccal regions generally displayed lower trends of decreasing bone density than the lingual sides. This incidence may be expected since the density of bone mass of the buccal cortex within the incisive and premolar region is known to be lower than the density of the corresponding lingual cortex [5].

Conclusions

We presented a method for virtual computation of bone density for dental implants. Small sample images for each implant were extracted from a three-dimensional CT scan. Bresenham’s line algorithm was implemented to collect density values along a designated distance (mm) from the apex of the implant. The density profiles were then mapped onto the 2-D sample image and shown together with the line integral as a general measure for osseointegration. Overall, the results show a good correlation between the virtual study and the mechanical test study [4].

From data collected by virtual and mechanical testing, it was evident that the bone density profile of the implant is site-specific and/or determined by the extent to which bone develops around the implant. The results obtained by the present study may serve as a platform for the future examination of the process of bone healing and development in vivo.

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