whose aim is the general optimization of preoperative planning to support non-invasive surgery.

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## Visualization of osseointegration of maxilla and mandible dental implants


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**Keywords** Medical imaging · 3D visualization · Volume rendering · Hybrid rendering · Osseointegration · CT scan · X-ray · Bone density measurement

**Purpose**

We present a new, hybrid visualization method that can assist in assessing the degree of osseointegration of dental implants.

**Method**

The lifetime and durability of dental implants depends primarily on the integration of the titanium socket in the bone. This process is called osseointegration. In order to assess the spatial distribution of bone matter near an implant site, a 2D or 3D radiographic scan can be obtained. X-ray absorption is a good indicator and directly correlated to bone density. Alternatively, a periometer, a percussive instrument for mechanical stress testing, can be used for assessing osseointegration. We have chosen to compare an established mechanical stress test to a 3D image-based method. In a cadaver study, a CT scan of the maxilla was obtained, and two nearly adjacent implant sites with somewhat complementary properties were selected as objects of study. The implant sites featured different degrees of osseointegration. The information from the image-based, virtual bone density measurement was then visualized and compared to the results from mechanical testing.The visualization method is based on radiographic imaging (CT scan), 3D volume reconstruction, and color coding of bone density. A two-dimensional cross-section of the implant site (similar to an X-ray image) was generated from the CT scan and superimposed on the image, making it easier for the radiologist to compare in a 2D cross-sectional profile the lingual and the buccal side of the implant. The distinction between bone deficiencies in the lingual or buccal side can also be made in the results from mechanical testing. On top of this, the 2D cross-sectional image was augmented by a 2D density profile obtained along a line in the cross-sectional plane along the lingual and the buccal side of the implant. This 2D density profile shows the degree of osseointegration on both sides of the implant (Fig. 1). The method provides both a 3D image of the titanium implant and the implant site (Fig. 2), and a 2D profile of the lingual and buccal side of the implant, exposing possible weaknesses in the supporting bone structure in a hybrid rendering (Fig. 3). The visualization procedure described here consists of 2-D cross-sectional

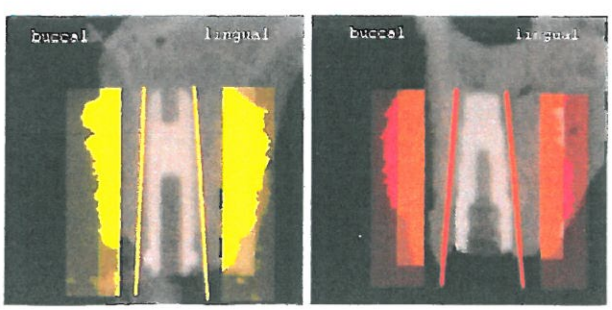


**Fig. 1** Bone density profiles for the lingual and buccal sides of two implant sites (with average shown as lighter area)

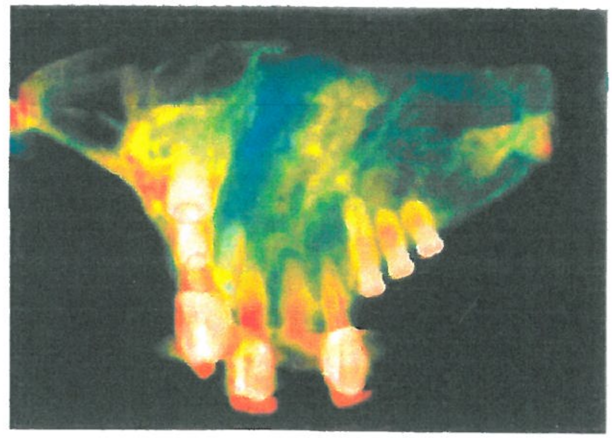

**Fig. 2** Maxilla (CT scan), alternative view

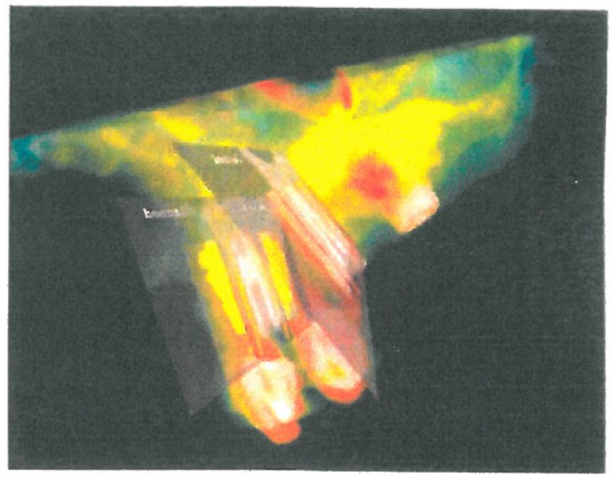

**Fig. 3** Combined volume and cross-section rendering of bone density for implant sites 10 and 12

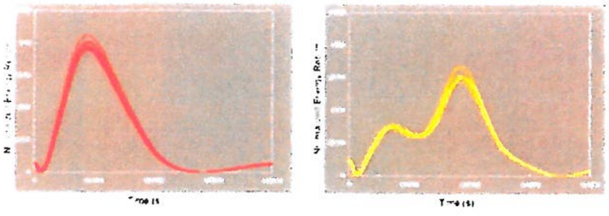

**Fig. 4** The normalized energy return curve for two implant sites. The periometer produces measurements for the energy return at each time of impact

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, computation of a bone density profile and line integral along the implant, and 3-D hybrid rendering of the implant site and the derived bone density information in its anatomical context. This method has been demonstrated to successfully enable the mapping of information derived from virtual bone density measurements onto a geometric object, thus providing the necessary information to relate information from mechanical testing or simulations to the respective site.

**Results**

A high-resolution CT scan of a cadaver was used as a reference data set. The hybrid view, a combination of 2D density profile and 3D color-coded density rendering, is very intuitive and easy to interpret. The 2D view was also useful for relating standard 2D X-ray imaging with enhanced 3D imaging of bone density. The image-based method was used for cross-validation of a mechanical testing method. The visual results obtained from our hybrid rendering methods led to the conclusion that one of the implant sites had lower bone density values on the lingual side at the dorsal none/implant interface where high-density values where expected. This conclusion was confirmed in the mechanical test, where a slight variation from a uniform bell-shaped curve was observed in the associated energy return plot (Fig. 4, left).

In addition, in the case of the bone density trend of implant site 10 lacking a prominent plateau, the associated energy return plot displays a fluctuation dip along the rise of the bell-shaped curve (figure 4, right). Both the virtual and mechanical sets of data indicate possible loss or insufficient bone mass along the same region.

The results from comparing our image-based visualization method to a mechanical method for assessing osseointegration show a good correlation between the two methods.

**Conclusions**

Since the two methods work in completely different ways (mechanical vs. radiographic) and the results came out the same, the results provide evidence that both methods for assessing the degree and location of osseointegration are valid. Further studies using additional scans on living subjects will be conducted to provide additional evidence. Cost-efficient X-ray imaging can be used to replace the simulated implant-aligned 2D X-ray views that were obtained from a 3D scan.

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## A novel laboratory training and evaluation technique of computer-aided oral implant surgery

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**Keywords** Laboratory training · Navigation · Implant surgery

**Purpose**

The implementation of computer-aided approaches in oral implant surgery requires knowledge and skills in diagnostic computed tomography (CT) imaging, 3D computed planning, and use of surgical navigation systems or CT-guided surgical templates. Further, aspects of accuracy and sources of error have to be learned for a successful and safe application of this sophisticated technology.

The objective of the presented work was to develop a laboratory training and evaluation technique of navigated oral implant surgery based on real clinical cases.

**Methods**

The following anonymous patient material of subjects that were previously treated by computer-aided implant surgery using CT-guided surgical templates fabricated via a multi-purpose navigation system was included: duplicated dental stone casts, individualized VBH registration mouthpiece and planning CT (high resolution spiral CT-scanning GE Lightspeed (GE Medical Systems Inc., Waukesha, WI, USA) or Siemens SOMATOM Sensation Open (Siemens AG, Munich, Germany) with slice thickness 1 mm).

Laboratory training consisted of managing a clinical case including (1) definition of the prosthodontic goal, (2) computerized surgical planning with respect to the individual anatomic and prosthetic situation, and (3) navigated model surgery in a dental dummy using the StealthStation® Treon™ plus optical based navigation system (Medtronic Inc., Louisville, USA).

For evaluation of the model surgery, a post surgical CT scan of the drilled dental stone casts with the individualized VBH mouthpiece and external registration frame is performed. The post-surgical data can be fused with the patient's presurgical planning CT using the navigation system's image fusion routine. The fiducial markers integrated in the external registration frame are utilized as corresponding points for the paired-point fusion algorithm. A Matlab script has been designed to compare the navigation system's settings-file containing the planned implant path with the updated settings-file obtained after the model surgery.

**Results**

Each step of computer-aided oral implant surgery can be simulated and trained: CT-imaging, computerized implant planning, registration and surgical navigation. All influential aspects of accuracy in computer-aided surgery can be studied: technical error (the intrinsic inaccuracy of the navigation system), registration error (the error of the image-to-patient transformation) and application error (the error of the surgeon's transfer of the surgical plan into reality as guided by the navigation system). Proper positioning of the stereotactic camera array, line of sight of tracking elements (universal tool adapter on the surgical drill) and the camera, use of different guidance views of the navigation software and navigational guidance skills are learned. Fusion of the CT of the drilled dental stone casts with the planning CT-data of the corresponding patient provides objective evaluation of model surgery including the following points: Euclidean distance at the implant tip, distance between the drilled implant axis and the planned axis, angular deviations, perforation of the alveolar inferior nerve or maxillary sinus, and damage to the adjacent roots of the teeth.

**Conclusion**

The presented learning and teaching module for oral implant surgery considers prosthodontics, CT-imaging, computerized oral implant planning, image-guided model surgery and post-procedural evaluation of accuracy based on a surgical navigation system and real patient material. A case library should be continuously enlarged to provide multiple training materials. The surgical navigation system is used for simulation of active image-guidance but can also be used for fabrication of CT-guided surgical templates for simulation of passive image-guidance. The current work-flow is limited to navigate drills of duplicated stone casts but can be extended to placement of study