THE USE OF COMPUTERIZED TOMOGRAPHY FOR DIAGNOSIS AND TREATMENT PLANNING IN IMPLANT DENTISTRY

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KEY WORDS

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Preoperative radiographic imaging of recipient sites for implant placement is imperative to obtain a functional and aesthetic implant-supported prosthesis. Although conventional radiographic techniques have inherent problems that restrict accurate imaging, the main drawback of panoramic and periapical radiography is the two-dimensional image. Computerized tomography provides cross-sectional radiographic images that facilitate proper assessment of potential recipient sites for implant placement. This paper reviews the role of computerized tomography in implant dentistry.

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INTRODUCTION

The progenitor philosophy of osseointegration[1,2] was based on the rehabilitation of completely edentulous patients with implant-supported prostheses.[3–5] Concurrent with the concept, the increasing worldwide acceptance of osseointegrated dental implants have eventually provided an alternative treatment for partial edentulism,[6,7] improved retention for maxillofacial prosthesis,[8] and anchorage for orthodontic treatment.[9,10] Currently, research and evolution in implantology have successfully resulted in the delivery to the patient of the permanent fixed prosthesis the same day of surgery.[11]

The long-term prognosis of an implant restoration depends on meticulous care taken in the diagnosis and the treatment planning for the patient. Contemporary surgical principles of osseointegration are based on a prosthetically directed patient assessment that emphasizes the role of the prosthodontist or the restorative dentist throughout the treatment when a team concept is followed. The placement of implants play a substantial role in the maintenance of osseointegration and for controlling the biomechanical load over implants; implant placement with reference to the predetermined type of prostheses diminishes the risk of complications that may compromise the longevity of the entire treatment.[12]

The radiographic evaluation (qualification and quantification) of bone density should be accomplished during patient assessment. One of the most significant factors that affect the outcome of the implant treatment is the quality of the surrounding bone.[11] From a biomechanical point of view, although 70% of the bone may well be able to withstand functional forces,[13] the implant success rate decreases as the bone density decreases.[14] Implants were demonstrated to have less micromovement, increased initial stability, and reduced stress concentrations in a high-density bone.[15,16] However, the loss of osseointegration may also occur when implants are placed in a high-density bone.[17]

Various radiographic imaging techniques have been used to determine the feasibility of implant placement[18,19] and posttreatment evaluation of hard tissues surrounding implants.[3,20,21] The technique utilized affects the quality of the radiographic image. However, none of the current imaging techniques are perfect enough to provide a high degree of interexaminer agreement. The value of any radiographic image depends on factors such as the amount of hard tissue imaged, the degree of definition, the amount of image distortion or lack of clarity, the superimposition of anatomic structures, and the amount of radiation exposure required to obtain an image.

Periapical, panoramic radiography and two-dimensional computerized tomography are more frequently used for diagnostic imaging than occlusal radiographs and lateral cephalograms. Accurate radiographic imaging is indispensable for the selection of appropriate implant size and is an invaluable guide for surgery.

When using panoramic imaging for diagnosis, one of the most frequent problems in the panoramic radiography is the loss of definition that occurs when the patient is improperly positioned in the machine or the curve of the mandible does not match the focal trough predetermined by the manufacturer.[19] The study has shown that only 17% of panoramic radiographs represent true osseous height on dried specimens.[22] Accordingly, due to the inevitable changes in the magnification on horizontal dimensions, the panoramic image does not match real dimensions. For the evaluation of the recipient sites and the determination of optimum implant dimensions, some implant manufacturers offer clear templates that accommodate the amount of distortion in panoramic radiography (approximately $\times$1.2 to 1.3). In the panoramic image, since the magnification in the vertical plane is relatively consistent with the object, it could be used safely to determine the length of implants.

While using intraoral imaging systems, the limited space within the oral cavity does not always match the size of films and may affect their positioning. The resorption of a completely edentulous mandible may eventually result in such a level that the superior genial tubercles may become the most superior aspect of the residual anterior alveolar ridge, and prominent mylohyoid and internal oblique ridges covered by thin and movable mucosa may be accompanying in the posterior region. In such circumstances, the insufficient height of the residual ridge interferes with proper film positioning, and obtaining the radiographic image of the apical portion of an implant or the mandibular canal becomes a hard task.

The slope of the palate is almost never exactly parallel to a film placed in the maxilla. Precise positioning of a film, particularly in the anterior maxilla, is also difficult. Thus the parallelization of a periapical film and the bone may require special attention in the maxilla. In the posterior mandibular region, the buccolingual location of the mandibular canal is of utmost importance since there is a potential risk of causing damage to the inferior alveolar nerve during surgery. However, neither the panoramic nor the periapical films can provide correct information.[22] The main drawback of both techniques for implant treatment is that the images are two-dimensional.

Among all current imaging techniques, two-dimensional computerized tomography (CT) is the most accurate in evaluating recipient sites and locating vital structures such as the mandibular canal.[23–25]

REFORMATTED AXIAL COMPUTERIZED TOMOGRAPHY

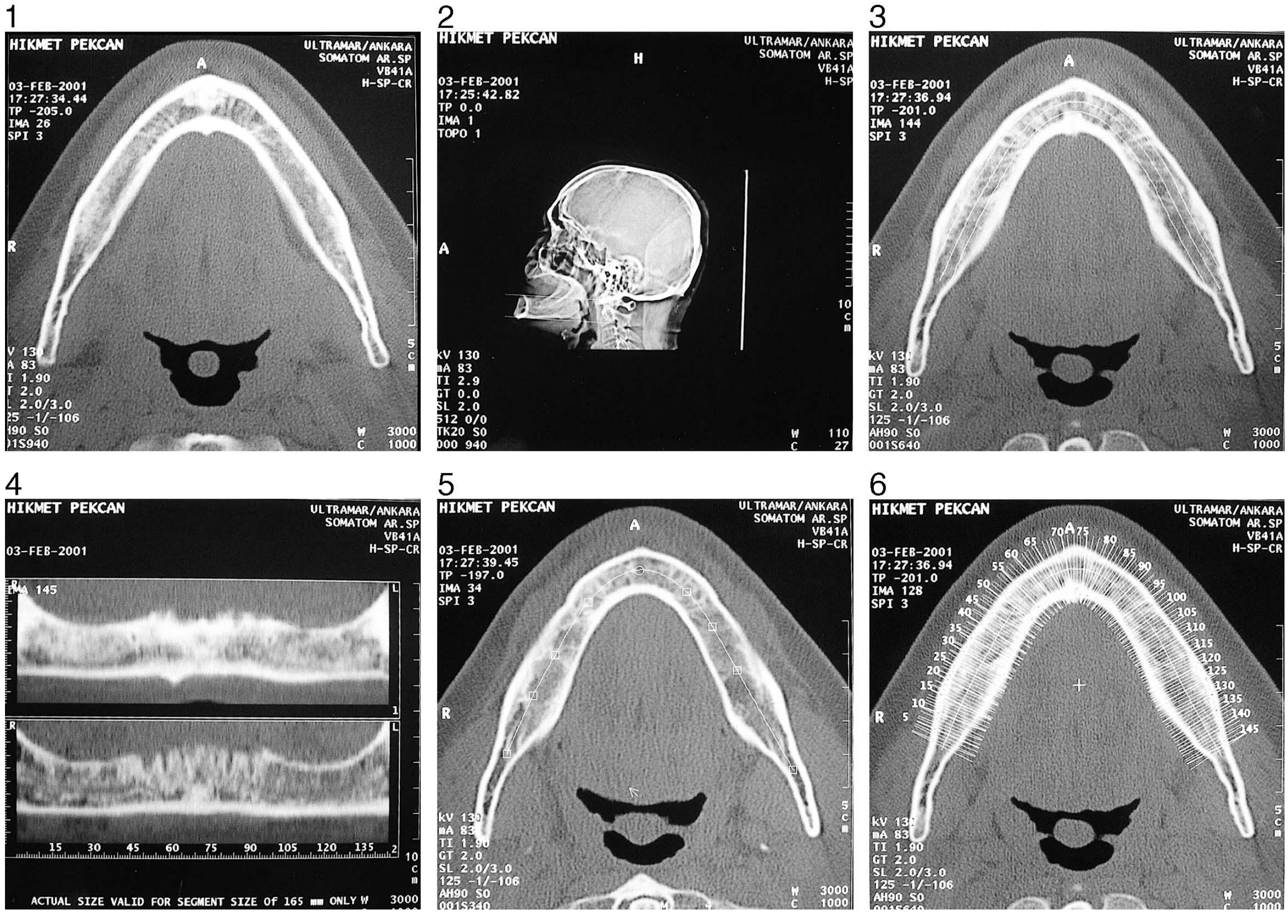
History

Three-dimensional radiographic imaging was first conceived in the early 20th century and was proved by calculating an infinite number of projections of the image of a three-dimensional object.[26] The original purpose of the use of CT scanners was to examine the human cranium.[27] Early devices provided 1 cm thick axial cross-sectional images, and by the 1980s technical developments resulted in obtaining 1.5 to 2 mm thick images. For several years, the technique was used to diagnose the lesions of the head and neck and for the evaluation of the anatomic structures of patients who were to undergo craniofacial surgery.

The manufacturers of subperiosteal implants introduced CT scans in dentistry and used axial images (Figure 1) for treatment planning.[28] Consequently, dentists recognized that the cross-sectional images of jaws provided detailed information about the potential recipient sites and were efficient in locating anatomic structures prior to the placement of root-form implants. In the last decade, CT scans have become one of the most frequently used imaging techniques for preoperative evaluation of the jaws before implant treatment. The first commercially developed program was DentaScan (General Electric, Milwaukee, Wis), which produced ''dentist-friendly'' images.[29–31] Currently, software programs used for dental purposes have similar scanning protocols.

Technical aspects

Bone is the structural foundation for dental implants. Vital bone continually undergoes processes of deposition and resorption in response to its mechanical environment. The density and the structural status of the bone is related to the amount of stress or strain induced within its structure during function.[32,33] The extracellular mineral matrix content of bone tissue affects the



FIGURES 1–6. FIGURE 1. Axial view of the mandible. FIGURE 2. Positioning of the edentulous mandible in the lateral digital scout view prior to scanning. FIGURE 3. Determination of panoramic views on the axial image of the mandible. FIGURE 4. Constructed panoramic images exhibit different vertical sections that reveal the morphological and dimensional differences within the mandible. Superimposed images in conventional panoramic radiography, however, may lead to misinterpretation. FIGURE 5. Axial view of the mandible with the superimposed curve that serves for the construction of cross-sectional images. FIGURE 6. One millimeter thick numbered sectiones (lines) perpendicular to the curve defines the locations and the planes in which cross-sectional images are formatted.

density, and thus the radiographic image. For instance, the increase in X-ray transmission of a tissue will result in an image that will appear darker. The more X rays are absorbed, the lighter the image will appear.[34–36] CT scans acquire digital information of an X-ray transmission through an object or attenuation by an object. During implant patient assessment, the technique offers the measurement of the mineral content of the cancellous bone independently of the surrounding cortical bone; a thin (approximately 1 mm) transverse section of bone is analyzed and the mineral content is calculated by using the linear attenuation coefficient (Hounsfield unit). These numbers range from −1.0 to +1.0, and each number dictates a different amount of attenuation of an X ray.

CT evaluation is required when the primary radiographic examination indicates the need for detailed information. Unlike other radiographic techniques that are used for diagnostic purposes only, CT scans can also be used for map-making of the treatment (Table 1). CT evaluation of a jaw for dental implantation requires images perpendicular to the curve of the alveolar ridge. By collecting data from a number of projected angles, it is possible to reconstruct images from calculated density values (mathematical algorithms) at a predefined location in the body. The resulting images that appear on the computer monitor are correct representations and allow measurement on either the monitor or on a photographic film. Despite the advantages of the technique, there are a number of disadvantages that must be taken into consideration (Tables 2 and 3).

During the procedure, the patient is instructed to recline supine on the scanner table. Current scanners provide high-resolution images. However, to provide artifact-free images, the patient's head should be immobilized during data acquisition. Thus, a head holder, chin strap, and sponges or cotton are placed around the patient's head to prevent motion. Initially, the

Table 1

The use of CT in oral implantology, particularly when conventional radiography indicates further evaluation

Indications
Prior to complete maxillary or mandibular subperiosteal implant treatment.
Prior to treatment of osseointegrated implants.
When measurement of exact available bone dimension is crucial.
Determination of the position of the mandibular canal, incisive canal, nasal cavity, and maxillar sinus.
Quantitative determination of bone mineral content.
Determination of the diameter, length, and three-dimensional positioning of implants.
Follow-up of patients who receive comprehensive treatment modalities (ridge maintenance and/or augmentation, sinus lift, marginal or segmental reconstruction).

Table 2

Advantages of CT during implant patient assessment

Almost accurate visualization of the hard and soft tissues without superimposition.
Reformatted images provide evaluation of the entire surface topography, contour, and density of bone. Location of vital structures, developmental defects, and pathologies may be determined.
Radiation dose delivered is low. Eyes and the thyroid gland are never directly exposed with the X-ray beam.
Allows accurate preoperative treatment planning (number, diameter, length, and positioning of implants).
Almost accurate measurement of available bone through successive cross-sectional images.
Since the head is relaxed and scanning is performed only in the axial plane, patient comfort is excellent. It is not time consuming for the patient.
Allows appropriate follow-up examination of titanium implants.

Table 3

Disadvantages of CT in implant dentistry

Slight movement of the head causes artifacts in the image.
Metallic restorations, root canal fillings, and nontitanium metallic surgical hardware cause artifacts.
The equipment is less accessible than machines for conventional radiography.
Higher cost.

patient's head is angulated so that the scanning is parallel to the existing occlusal plane or the superior surface of the alveolar ridge for completely edentulous patients (Figure 2). If the parallelization cannot be established, the gantry may be angled. Locating the scanning plane parallel to the occlusal plane minimizes the required number of scans to evaluate a jaw and diminishes image degradation caused by existing metallic restorations. The patient is instructed to stay motionless. Consequently, a digital lateral radiograph (lateral scout view) is made to determine the limits of scan volume. If the image is not acceptable, the patient's head must be repositioned and the lateral scout view should be repeated. After the scanning procedure, the technician uses the dental CT program to define the plane and location of the reformatted panoramic view by using this curved line superimposed to the arch of the mandible or the maxilla (Figures 3 and 4). Best results for multiplanar reformation are obtained when the axial image illustrates the roots of the existing teeth and full contour of the jaws (Figure 5). Then the CT program automatically draws several lines perpendicular to this curve, which denotes the location of cross-sectional images to be obtained (Figure 6). When there are multiple contiguous cross-sectional images, the computer can reconstruct the images in any plane by selecting specific information from stored data sets.[37–39]

Since the determination of the mandibular canal is important, contiguous 1-mm slices should be obtained for the mandible. It is adequate to assess the maxilla every 1.5 mm. However, 1 mm thick images also help a precise location of the maxillary sinus (a total of 20 to 30 slices).[28] Although cross-sectional images for the mandible comprise the entire height of the corpus, maxillary images end at the most cranial extent of the hard palate (Figure 7). The evaluation of available bone in thin multiplanar images offer exact determination of the location of the anatomic structures and the bone density surrounding the implant.[22,40–42]

The reconstructed or reformatted images can be transferred to a film, magnetic tape, optical disk, or photographic paper for the patient record. The structures may be determined and evaluated on planes by using thick marks that appear on axial, panoramic, and cross-sectional image borders. Additionally, a millimeter scale displayed on the images allows the dentist to measure dimensions of the available bone. Such images allow measurement either on the monitor of the computer or on the film. Dentists usually prefer life-size films.

The absorbed radiation dose by using CT imaging is a concern. During dental radiographic procedures, organs most susceptible to the side effects of radiation are the thyroid gland, brain, active bone marrow, lymphatics, and salivary glands. The radiation dose delivered has been investigated during CT examinations for implant patient assessment.[43–45] In these studies, differences in the methods or machines affected the quantitation of the radiation dose absorbed by the organs. Thus, it does not seem rational to compare the results. However, although the biologic effects of radiation are known, the risk associated with CT is assumed to be low.

The use of CT in oral implantology

The basic purposes for the use of CT are the following: (1) the determination of the quality and the quantity of bone; (2) the evaluation of potential recipient sites for implant placement, particular-

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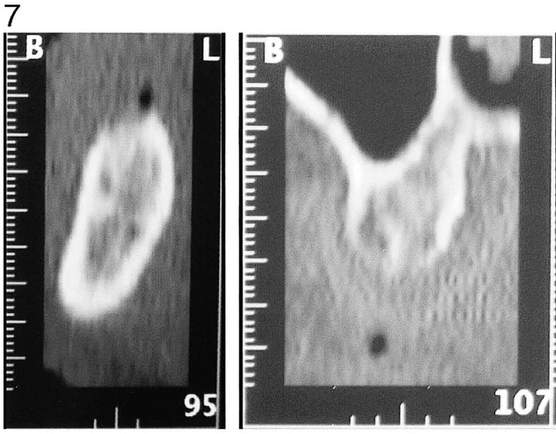

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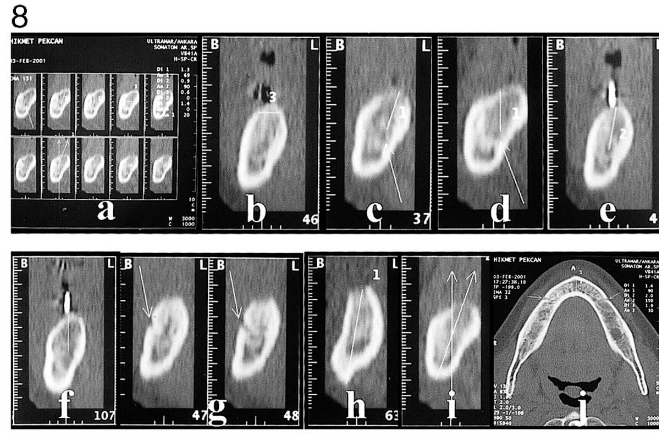

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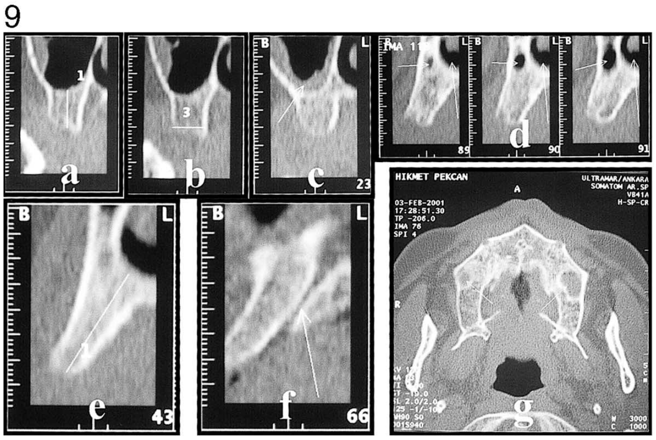

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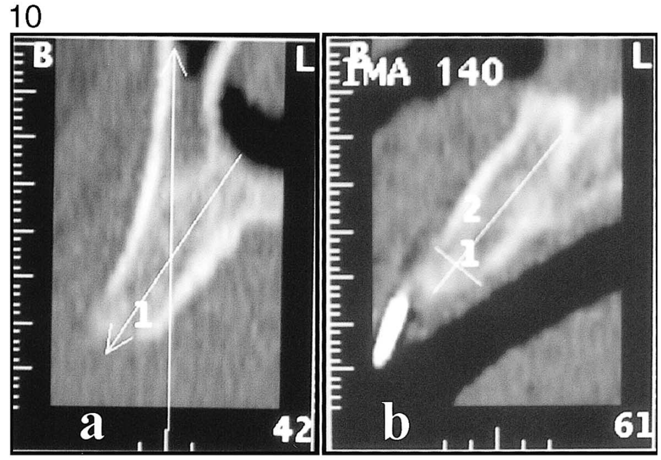

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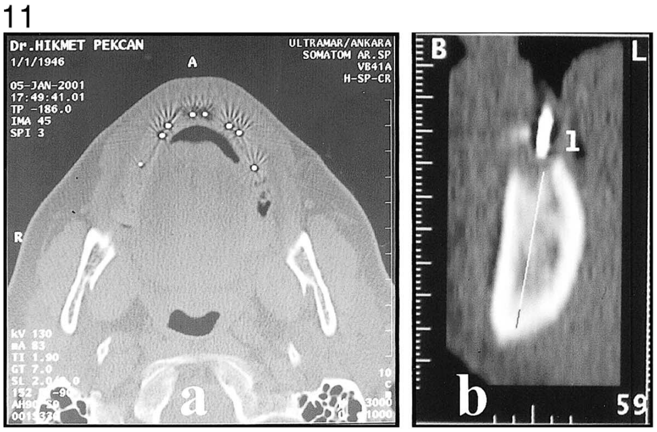

FIGURES 7–11. FIGURE 7. (a) Optimal mandibular cross-sectional image. (b) Optimal maxillary cross-sectional image. FIGURE 8. (a) Various measurements may be performed on the cross-sectional images to evaluate available bone width, height, and angulation in accordance with vital structures such as the mandibular canal. (b) Measurement of the buccolingual dimensions of the alveolar process. (c) and (d) Measurement of the distance between the crest of the alveolar process and the mandibular canal. Since the distance between (c) and (d) are different, optimum implant angulation and positioning should be provided by using a dual purpose stent containing radiopaque markers. (e) Measurements should be performed to provide optimum length, angulation, and buccolingual positioning of implants. Note that the measurement in the cross-sectional image is inappropriate. (f) Correct measurement. (g) Identification of foramen mentale. (h) The measurement of the height of the mandible on a cross-sectional image 2 to 3 mm anterior to the anterior loop of the mandibular canal. (i) The measurement of the bone angulation in the posterior mandibular region. (j) The measurement of the interforaminal distance (Di 2 + Di 3 = 3.9 cm) and buccolingual width in the anterior mandible (Di 1 = 1.4 cm). FIGURE 9. (a) Measurement of the distance between the alveolar crest and the sinus floor to determine available bone height in the posterior maxilla. (b) Measurement of the width of the alveolar process in the posterior maxilla. (c) Cross-sectional view of a thick sinus membrane. (d) Cross-sectional view of the maxillary sinus and nasal cavity. (e) Measurement of the distance between alveolar crest and floor of the nasal cavity in a cross-sectional image of the anterior maxilla. (f) Cross-sectional view of the incisive canal. (g) View of the sinus floor in an axial image. FIGURE 10. (a) The bone angulation in the anterior maxilla affects positioning of implants and final aesthetics of the restoration. Figure shows measurement of labiopalatal angulation. (b) Determination of the available bone width and height. Selection of an angulated abutment may also be provided by using a radiopaque marker placed parallel to the long axis of the predetermined implant restoration. FIGURE 11. (a) Axial view of the mandible. Note that radiopaque markers have been used to evaluate potential recipient sites for implant placement. (b) The image of a 1 mm thick radiopaque marker can only be viewed in 1 section of the scan images and provides accurate evaluation of the predetermined implant axis and the area representing the bone structure at the central section of the implant.

ly with stents; (3) evaluation of intraosseous pathologies; (4) and follow-up of regions where extensive surgery is performed.

As mentioned previously, accurate qualification and quantification of bone may be provided through the use of software programs that have been developed in the last decade. Bone height, width, and angulation can be easily measured directly on the computer by the help of dental CT software (Somatom AR.SP VB21A, Siemens, Munich, Germany; Figures 8 and 9). Evaluation of bone for implant placement may be provided through the use of radiographic or dual-purpose stents. Since the ultimate objective of implant placement is a functional, aesthetic, and durable restoration, the imaging of potential recipient sites should provide accurate information that facilitates precise placement of implants in a correct three-dimensional position.[46] Placement of implants in the anterior maxillary region requires special attention. Regional soft tissue and bone contour may affect the emergence profile and the final appearance of the prosthesis. Implants overangulated toward the labia can lead to aesthetic disharmony. For extremely malaligned implants, an opening for screw access on the facial surface of the prosthesis or its complete removal may be indicated. Implants placed in the interproximal areas of a prosthesis may cause aesthetic and hygiene problems, and implants placed too lingually usually result in a bulky prosthesis with an unfavorable lingual contour that may also interfere with speech (Figure 9).

A stent is an appliance used either for radiographic evaluation during treatment planning for the implant patient or during surgical procedures to provide optimum implant placement. In comparison to conventional radiographic stents, dual-purpose stents offer the advantage of transferring the CT data onto the same stent for surgery. However, since errors in converting the stent may lead to malalignment of the implants, the angle of the radiopaque markers should provide ease in reorienting the surveying table if guide channel preparation must be performed in a different angle. Additionally, the radiopaque marker(s) should provide an accurate transfer of the two-dimensional information to the three-dimensional stent throughout the entire procedure.

Radiopaque markers are helpful guides to evaluate the bone in the recipient area. The use of 1 mm thick pins placed in the center of the occlusal table of a prosthetic tooth in the stent enables the doctor to view the actual line of implant axis at only 1 section of the scan images (Figure 10). Thus minor changes can be precisely performed both in the location and the angulation of implants. Such images provide accurate information about the quality and the quantity of the bone surrounding the thickest section of the implant. Radiographic or dual-purpose stents with radiopaque markers such as gutta percha,[47–50] metal bearings,[51] lead foil,[52] metal rods, pins or tubes,[46,53–56] and resin teeth made with barium sulfate[57] are invaluable guides for the determination of the dimension, location, and angulation of the implant according to available bone, vital structures, and the predesigned prosthesis (Figure 11). Utilization of improper surgical guides may result in malaligned implants, particularly in the posterior region when low bone density exists. Implant channels must be created with maximum care and an effective and simple technique for simultaneous channel formation, and proper implant placement must be developed.

Three-dimensional CT images may be used for follow-up of intraosseous pathologies that may compromise implant treatment. Although three-dimensional images are not necessarily used for implant treatment, such images may be useful to determine cystic lesions in the lingual salivary glands in the mandible, dentigerous cysts, or developmental bone defects.[58–61] CT has also been used for follow-up of patients who undergo surgical interventions such as graft applications[62] or distraction osteogenesis.[63]

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