3-D imaging in the context of treatment planning

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3-D imaging has revolutionized pre-treatment case analysis and treatment planning.

Cone beam computed tomography (CBCT) is becoming the emerging standard of care for diagnostics.[1] This article focuses on the benefits of CBCT in the context of "restorative leadership" in implant therapy. It also addresses the role of CBCT imaging in interdisciplinary dentofacial therapy for skeletally mature patients requiring orthodontic therapy.

CBCT and "restorative leadership"

CBCT increases the amount of pre-operative information related to "condition" and "position" of regional anatomy and key structures. It provides valuable information on alveolar bone volume and shape as well as vital landmarks such as the inferior alveolar nerve or maxillary sinus, which cannot be interpreted to anywhere near the same level of accuracy when 2-D imaging is used. Unfortunately, without "restorative leadership" – in other words: without a "prosthetically driven treatment approach incorporated into the 3-D planning software" – meaningful 3-D imaging data interpretation will fall short of its true interdisciplinary potential.[1] "Restorative leadership" means that the prosthetic outcome of implant treatment determines the surgical requirements, which the implant surgeon is expected to follow and and to which he is accountable. It also provides a platform for realistic outcome expectations to be discussed among the treatment team prior to irreversible intervention. Inherent to this interdisciplinary process, the restorative specialist or prosthodontist must assume the key leadership role by determining the outcome goals of the case from a prosthetic, occlusal, facial esthetic and airway perspective.[2] CBCT together with planning software can form a reliable basis for interdisciplinary collaboration.
The diagnostic wax up/set ups, which are incorporated into the CBCT imaging, allow meaningful treatment planning to include the shape and contour of the teeth, the emergence form of the teeth and gingiva and the volume and appearance of the soft-tissue. On the basis of Mecall's proposed case type patterns[3], five different treatment planning modalities can be distinguished.[1] In all cases, the wax-up is either the basis for a scanning appliance from radiopaque material, which the patient wears while the CBCT imaging is performed, or, more contemporarily, the wax-up (tooth form or fully contoured) is duplicated into a stone-cast, which is optically scanned and combined with the patient's CBCT image dataset into the planning software.

The five case type patterns in implantology

Case type pattern I: The patient's dental and surgical anatomies are within normal limits. Teeth can be replaced without modifying the surrounding bone or soft-tissue. In other words, the pink esthetics are acceptable, and the white esthetics alone require modification. The diagnostic wax-up in this case involves the missing tooth alone (or not, such as in the case of an immediate extraction and implant placement where the white and pink esthetics are ideal). Information from the wax-up is either used for fabrication of a scanning appliance, or the wax-up is optically scanned and merged into the virtual 3-D plan.

Case type pattern II: The dental anatomy is sufficient, but there are minor augmentation needs to the surgical anatomy (bone or soft-tissue), e.g.,

1a) Crestal and radicular dentoalveolar zone
1b) Thick/thin phenotype with a thick crestal and a thin radicular zone
1c) Thin/thin phenotype with a thin crestal and a thin radicular zone

because of slight facial bone loss, gingival asymmetry, etc. In some cases, such as contour deficiencies, the wax-up has to be fully contoured (replace teeth and soft-tissue). This information is included in the virtual 3-D planning. If the phenotype is spatially and volumetrically correct, a tooth-form wax-up may suffice.

Case type pattern III: These cases are situations of primary horizontal bone loss with some vertical change. The patient's dental anatomy is within the normal limits, but the surgical anatomy (bone or soft-tissue) requires primarily lateral ridge augmentation. A full contour wax-up is required, which, after being transferred to the 3-D image, helps to identify appropriate surgical and prosthetic options, including bone or soft-tissue augmentation.

Case type pattern IV: Modification of both the dental and surgical anatomy is needed, because of vertical and horizontal bone loss, supraeruption, altered occlusal vertical dimension, etc. A full contoured wax-up is required and possibly even a trial tooth set-up, depending on the extent of partial edentulism and intermaxillary conditions. These cases generally present with primary vertical bone loss and some degree of horizontal atrophy.

Case type pattern V: The patient suffers from significant dental and anatomic shortcomings such as an atrophic, completely edentulous ridge. A trial tooth set-up is needed, as the patient may lack adequate tooth and lip support to determine the correct occlusal vertical dimension, phonetics and esthetic outcome goals. In these cases, advanced horizontal and vertical bone loss patterns are evident. In the case of an existing well-fitting denture and prosthodontic parameters acceptable, the denture may either be duplicated into a barium differential gradient (teeth vs. soft-tissue) scanning appliance or, as is more contemporary, be used as part of a dual-scan imaging technique.

The CBCT-based virtual treatment plan can be transferred to "real-life surgery" via computer-generated stereolithographic drilling guides or through dynamic surgical navigation[5]. This approach has the potential to reduce intraoperative error. Meanwhile, several levels of control can be distinguished – from virtual planning with CBCT in combination with a conventional surgical guide, to a fully guided approach, where the drilling guide f ully determines the apico-coronal, buccolingual and mesiodistal orientation of the implant. Certainly, the more control the computer-generated surgical guide is entrusted for final implant position, the more important accurate clinical and prosthetic planning becomes. Guided surgery can be "accurately accurate" or "accurately inaccurate". Limited bone volume, higher anatomical risk, multiple implants, flapless surgical intervention and aesthetically demanding situations require precision and accuracy at each step to limit error.

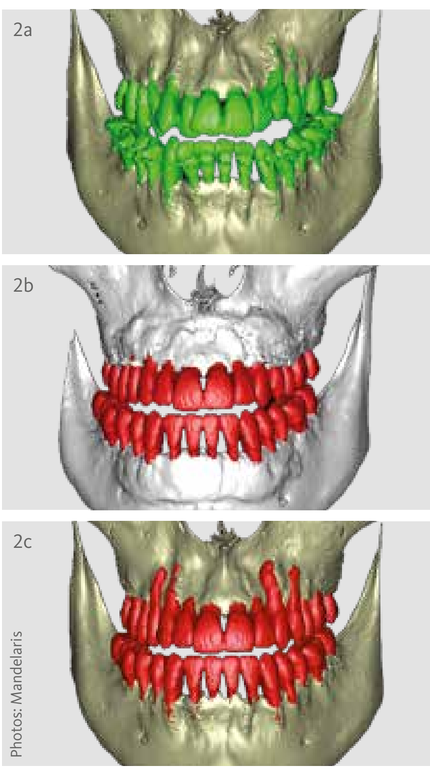
A CBCT-based classification of dentoalveolar bone

In the context of orthodontic treatment for skeletally mature patients, evaluation of the dentoalveolar bone thickness in both the crestal and the radicular zone can be crucial to minimize the risk for iatrogenic sequelae. According to a CBCT imaging study evaluating nearly 500 patients, average facial bone thickness was determined to be less than 1 mm in 90 % of the patients evaluated (maxillary first molar to maxillary first molar)[4] – underscoring the vulnerability and limitations of the periodontium to certain tooth movements.

In 2013, we published a CBCT-based classification system which categorizes crestal and radicular dentoalveolar bone and helps establish risk prior to interdisciplinary dentofacial therapy cases involving tooth movement.[5] The system defines two zones (crestal and radicular) and describes four different dentoalveolar bone phenotypes [thick (>1mm) or thin (<1mm) by classifying bone thickness in each zone **(fig. 1)**[5]**:**

> a thick crestal zone and a thick radicular zone
> a thin crestal zone and a thick radicular zone
> a thick crestal zone and a thin radicular zone
> a thin crestal zone and a thin radicular zone

The use of this classification system allows a risk assessment to occur prior to orthodontic tooth movement and can help with the decision as to whether the patient is a candidate for conventional orthodontic therapy or whether alternative orthodontic approaches, such as surgically facilitated orthodontic therapy (SFOT), should be considered.



2a) CBCT showing the pre-treatment tooth position and thin facial bone

2b) Final tooth position and bone volume after surgically facilitated orthodontic therapy

2c) Virtual experiment: combination of the patient's pre-treatment bone anatomy and post-orthodontic tooth positioning (illustrating the loss of both facial bone and iatrogenic sequela that would likely have occurred with a conventional orthodontic therapy)

What is surgically facilitated orthodontic treatment?

It is well known that moving teeth outside the "orthodontic walls" leads to loss of alveolar bone and increases the risk for iatrogenic sequela.[6] However, in the management of malocclusions with dentoalveolar bone deficiencies, leaving the teeth inside the native bone envelope can mean that permanent teeth have to be extracted in order to gain space and correct arch forms.

Retractive orthodontic schemes to correct the crowded/constricted arch form may induce other problems such as alveolar bone loss and/or result in a net loss of oral cavity volume, which is counterproductive for anterior tongue posturing.[7]

Surgically facilitated orthodontic therapy enables management of crowding and dentoalveolar bone deficiencies by arch expansion (vs. retraction), which enhances the orthodontic walls through bone grafting **(fig. 2).** This approach allows orthodontic decompensations to occur for optimal facial esthetics and function as well as optimization of anterior protected articulation parameters and improvement of oral cavity volume (which may have a positive effect on measurable airway parameters during sleep, such as oxygen saturation, baseline drift, RDI/AHI, cycling time (%) and heart rate). Corticotomy based SFOT surgery involves corticotomies and dentoalveolar bone decortication as well as bone augmentation to enhance the orthodontic walls.[8,9] It is periodontal ligament mediated and dependent.

CBCT for informed consent

Perhaps the least appreciated benefit of CBCT imaging is the ability to consult with a patient in an atmosphere of complete disclosure. Informed consent becomes more transparent, and the playing field for accountability is level, because the same information for analysis and treatment planning is available for all participating team members. Additionally, we use CBCT in our practice for getting the patient involved in a "co-discovery" approach to their problems and concerns. Educated patients will generally make the best health care decisions after understanding all options.

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