The process of accumulating patient information to determine which course of dental implant treatment should be considered can be described under the category of pre-surgical prosthetic planning. The first step in patient evaluation involves conventional periapical radiographs, panoramic radiographs, oral examination, and mounted, articulated study casts. These conventional tools allow the clinician to assess several important aspects of the patient’s anatomical presentation, including vertical dimension of occlusion, lip support, phonetics, smile line, overjet, overbite, and ridge contours, and to obtain a basic understanding of the underlying bone structures. The accumulation of preliminary data afforded by conventional diagnostics provides the foundation for preparing a course of treatment for the patient. However, the review of findings is based upon a 2-D assessment of the patient’s bone anatomy and may not be accurate in the appreciation of the spatial positioning of other vital structures, such as the
incisive canal, the inferior alveolar nerve, or the maxillary sinus. In order to understand each individual patient’s presentation fully, it is essential that clinicians adopt an innovative set of virtual 3-D tools. Through the use of advanced imaging modalities, new paradigms have been established that, in the author’s opinion, will continue to redefine the process of diagnosis and treatment planning for dental implant procedures for years to come.

Without the application of computed tomography (CT) or lower radiation dosage cone beam computed tomography (CBCT), an understanding of the 3-D anatomical reality cannot be accurately determined, potentially increasing surgical and restorative complications.

The utilisation of 3-D imaging modalities as part of pre-surgical prosthetic planning can take several paths as demonstrated in the flow chart. The first involves acquiring a 3-D scan directly, without any prior planning or ancillary appliances. The scan process can be accomplished at a local radiology centre or via an in-office CBCT machine, now widely available. The scan itself can be completed within several minutes. Once the data has been processed, it can be viewed via the native software of the CBCT machine used and evaluated for potential implant recipient sites, followed by the surgical intervention. A second path requires the fabrication of a radiopaque scanographic appliance that incorporates vital restorative information and will be worn by the patient during the acquisition of the scan. In this manner, the tooth position can be evaluated in relation to the underlying bone and other important anatomical structures, such as the maxillary sinus or the inferior alveolar nerve. The scan data can again be visualised via the CBCT machine’s native software and a plan can be determined based directly upon the restorative needs of the patient.

The scan data is formatted into a non-proprietary data interchange protocol referred to as DICOM (Digital Imaging and Communications in Medicine). The DICOM data can be exported for use in third-party software applications that incorporate additional tools to aid clinicians in the diagnosis and treatment planning functions.

The use of interactive treatment planning has expanded dramatically in the past ten years as computing power has increased exponentially. There are at least two paths that can be taken once a virtual plan has been established. The first allows the data to be assessed, providing important information to the clinician who will perform the surgical intervention free-hand based upon the software plan. This has been termed CT-assisted intervention by the author. The second path involves the fabrication of a surgical guide or template that is remotely constructed from the digital plan usually through rapid prototyping or stereolithography. This method has been described as CT-derived template-assisted intervention and is considered to be more predictable than any previous methods. The use of advanced imaging modalities for pre-surgical prosthetic planning is essential for any type of implant surgical and restorative interven-
3-D planning concepts for the mandible

Regardless of the image acquisition process, there are four standard views that need to be fully appreciated in the diagnosis phase. These include the cross-sectional (A), the axial (B), the panoramic (C), and the 3-D reconstructed volume (D) as seen in Figure 1. The ability to interact within these images differs from software to software. It is the ability to visualise 3-D data with improved tools that empowers clinicians to assess individual patient anatomy. The cross-sectional slice is important for the assessment of the facial and lingual cortical bone plates, the intramedullary bone, and the positioning of teeth within the alveoli. The axial view allows inspection of the entire upper or lower jaw, the maxillary sinus volume, the position of the incisive canal in the maxillae, and the mental foramina in the mandible. The panoramic view is an overall scout image, and can be helpful in tracing the mandibular nerve, and assessment of the maxillary sinus floor near the nose region. The 3-D reconstructed volumes are invaluable in the planning process and in communicating information to the members of the implant team, including the patient and the dental laboratory technician who will fabricate the final prosthesis. These images are especially useful, as they are most readily understood and appreciated.

As represented in the flow chart, a patient may be sent to a radiology centre for a CBCT scan of the mandibular arch without a scanning appliance. The 3-D reconstructed volumes are easily understood and interpreted for the mandible (Figs. 2a–c). In the case demonstrated, there were several hopeless anterior teeth that were planned for extraction. The extent of the bone loss can be appreciated by the clinician and demonstrated to the patient as an excellent educational and communication tool. The virtual mandible can be rotated to reveal all views of the patient’s individual anatomical presentation (Figs. 3a & b). With innovative software tools, the teeth can be virtually extracted in the 3-D reconstructed volume, aiding the clinician in understanding the local anatomy to identify potential implant recipient sites (Figs. 4a & b). In this example, the alveolar ridge narrowed considerably at the crest. In order to facilitate implant placement, the ridge required an alveolec- tomy, reducing the ridge by approximately 8–10 mm.

Advanced software applications allow for the bone to be sectioned based upon the desired plan. A bone reduction template pioneered by the author can be simulated by the software and then fabricated to assist in the bone removal (Figs. 5a & b). The reduction template fits over the ridge, allowing complete visualisation of the residual bone to be sectioned from the alveolar ridge. The flattened ridge can also be simulated, greatly enhancing the clinician’s appreciation of the remaining...
bone topography (Figs. 6a & b). The amount of bone to be removed can be visualised as shown in Figure 7a and then assessed with realistic manufacturer-specific implant placement in the bone (Fig. 7b). The occlusal and facial views reveal the new width of available crestal bone for implant placement (Figs. 8a & b). The visualisation of the bone crest can aid in the determination of ideal implant recipient sites. However, it must be noted that all other views must be considered to appreciate adjacent vital anatomical structures and the remaining topography of the anterior mandible before any plan can be finalised. Several different options can be quickly simulated and then discussed with the patient and all members of the implant team. The use of a bone reduction template can facilitate the accurate removal of bone and the immediate placement of implants, eliminating the need for two separate surgical interventions and thus minimising patient morbidity.

The initial plan in the case demonstrated was for the patient to receive an implant-retained overdenture. Therefore, recipient sites were determined based upon the available bone in the mandibular symphysis between the right and left mental foramina, which were assessed in the axial and cross-sectional views. While it is possible to fabricate an overdenture design with implants in the posterior region of the mandible, the usual position of implants is within the symphysis region. The choices were to place two implants, three implants, or four implants between the two mental foramina (Figs. 9a–d). The symphysis area is not free from risk. A cross-sectional view is necessary for an appreciation of the thickness of the facial and lingual cortical bone plates, and for assessment of the trajectory and topography of the anterior mandible. In addition, there are important vessels in the region that have been shown to cause severe haemorrhaging if perforated. These vessels may differ from patient to patient and underscore the importance of a 3-D diagnosis. In this case, two such vessels were found in the midline area of the symphysis (red arrows) as seen in the cross-sectional view, which also revealed the extensive bone loss surrounding the hopeless teeth (yellow areas; Fig. 10).

Virtual realistic implants were simulated in the residual alveolar bone (Figs. 11a–d). A simulated surgical template was fabricated for the desired implant positions and rested on the reduced bone both facially and lingually. At the midline, where the vital vessels resided, it was elected not to place an implant to avoid potential surgical complications (Fig. 12). The simulated bone-borne surgical template was visualised in various 3-D reconstructed volumes (Figs. 13a–c). The first two revealed a midline horizontal stabilisation screw (Figs. 13a & b) and the last showed a standard bone-borne template without fixation (Fig. 13c).

In order to demonstrate the capabilities of the new digital paradigms, five virtual implants were placed into the initial anterior alveolar ridge after the teeth had been extracted virtually (Fig. 14a). The positions of implants can be further enhanced by placing yellow abutment projections that extend above the occlusal plane. Using selective transparency, the various structures can be adjusted in opacity and translucency. Using advanced software simulation, horizontal osteo-
tomies to allow the implants to be placed in the same vertical position in the newly reduced ridge were illustrated (Fig. 14b). Implant-to-implant relationships can be evaluated in all dimensions (Figs. 15a & b). In addition, it is important to provide ample clearance between the most posterior implants and the inferior alveolar nerve and mental foramen. Once the positions of the implants have been finalised, a surgical guide can be simulated (Figs. 16a & b). Note that the implants were all parallel, which can aid in laboratory fabrication for overdentures and in achieving passive fit for fixed frameworks (Fig. 16c). The relationship between the original tooth position and the simulated implants can be appreciated in Figure 16d. If a fixed detachable hybrid, full-arch CAD/CAM zirconia restoration, or an immediate restorative protocol is desired, the ability to simulate implant position with an accurate consideration of the desired tooth position will enhance the surgical, restorative and laboratory phases of treatment.

**Conclusion**

The advent of complete denture fabrication has evolved into the adoption of overdenture concepts for both natural and implant-retained restorations. Conventional prosthodontic protocols have been developed to aid in the diagnosis, treatment planning and laboratory phases of the reconstruction. These include conventional periapical radiographs, panoramic radiographs, oral examination, and mounted, articulated study casts. Using these, the clinician can assess several important aspects of the patient’s anatomical presentation, including vertical dimension of occlusion, lip support, phonetics, smile line, overjet, overbite, and ridge contours, and can obtain a basic understanding of the underlying bone structures. The accumulation of preliminary data afforded by conventional diagnostics provides the foundation for preparing a course of treatment for the patient. However, the review of findings is based upon a 2-D assessment of the patient’s bone anatomy.
In order to understand each patient’s presentation fully, advanced 3-D imaging modalities are essential. This article has illustrated the use of various innovative virtual 3-D tools.

The application of CT or lower radiation dosage CBCT provides clinicians with an accurate understanding of the 3-D anatomical reality of our patients as an aid in providing state-of-the-art treatment. Implants will be better positioned, with fewer surgical and restorative complications, and reduced laboratory remakes based upon these diagnostic tools. The benefits will enable clinicians to better understand the relationship between patient anatomy and the desired restorative outcomes in the process of achieving true restoratively driven implant reconstruction. The ability to utilise digital imaging and treatment planning technology is now within the reach of many clinicians through the various software products on the market. In addition, there are many third-party outlets online that enable clinicians to upload their DICOM data for evaluation, processing, treatment planning, and even surgical template fabrication.

In many case presentations, a reduction of the alveolar crest is an essential part of the surgical phase to achieve adequate width of the bone for implant placement. It is now possible to plan for accurate bone reduction with the full knowledge of the impact on the inter-arch space and occlusal requirements. The advent of the bone reduction template provides one additional digital solution that can also result in reduced patient morbidity, especially when the process can be completed in one surgical procedure. New paradigms have been established that, in the author’s opinion, will continue to redefine the process of diagnosis and treatment planning for dental implant procedures, both removable and fixed implant-retained alternatives, for years to come.

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Dr Ganz delivers presentations worldwide on both the surgical and restorative phases of implant dentistry, and has published extensively on these topics. He is considered one of America’s leading experts in the evolution of computer utilisation and interactive software for diagnostic and treatment planning applications using CT and newer-generation CBCT imaging modalities.