Introduction
Rehabilitation of the edentulous alveolar ridge with dental implants is a common treatment modality. Successful esthetic and functional implant rehabilitation relies on sufficient bone volume in the vertical and horizontal dimensions, adequate bone contours, ideal implant positioning and angulation, periodontally healthy peri-implant soft tissue, adequate soft tissue contours, and appropriate emergence profile. Following tooth loss or trauma, however, both hard and soft tissue ridge deficiencies can develop. Reduction in the alveolar ridge is common following tooth extraction and it can occur rapidly. Additionally, the presence of anatomic structures including the maxillary sinus, inferior alveolar nerve, and anterior loop of the mental foramen can limit the osseous dimensions available for implant placement.

Hard tissue augmentation of a deficient ridge is a common procedure employed to facilitate dental implant placement. Ridge augmentation allows for use of longer and wider implants and placement of implants in the ideal restorative position. There are multiple treatment options available to correct osseous ridge deficiencies. Prior to bone augmentation, the alveolar ridge deficiency must be properly assessed to help determine the best treatment option.

Alveolar Ridge Deficiency Classification
A variety of ridge deficiency classification schemes have been described pertaining to both hard and soft tissue defects. Lekholm and Zarb (1985) presented a classification scheme to describe hard tissue deficiencies. The classification system describes five groups of jaw shapes to include: intact ridge (A), moderate ridge resorption (B), advanced ridge resorption extending to the basal bone (C), initial resorption of the basal bone (D), and extreme resorption of the basal bone (E).

Misch and Judy (1985) presented a similar classification of ridge resorption with suggested augmentation and prosthodontic treatment modalities for each category. This classification takes into account only hard tissue defects and was stratified based on divisions that describe the natural bone resorption pattern. The divisions represented abundant bone (A), marginally sufficient bone (B), compromised bone (C), and deficient bone (D). Furthermore, the authors suggest appropriate treatments for each classification.

Seibert (1983) presented a classification of ridge defects to assess deficiencies in form, function and esthetics. The classification takes into account both hard and soft tissues. Seibert Class I defects describe ridges deficient in the horizontal dimension. Seibert Class II defects describe ridges deficient in the vertical dimension. Seibert Class III defects include ridges deficient in both the horizontal and vertical dimensions. The Seibert classification does not provide any quantification of the magnitude of ridge deficiencies.

Allen et al. (1985) provided a modification to the original Seibert classification by additionally describing the magnitude of the ridge defect. Allen Type A classification represents vertical ridge deficiency. Allen Type B classification represents horizontal ridge deficiency. The Allen Type C classification describes a combined horizontal and vertical ridge deficiency. The severity of the ridge defect is further classified as mild (<3mm), moderate (3-6mm), and severe (>6mm), as compared to the contours of the adjacent ridge.

When the Seibert (1985) and Allen (1985) classifications were developed, they were meant to aid in the selection of appropriate soft tissue augmentation modalities to improve upon the esthetics in the pontic design. With the advent of guided bone regeneration, further subdivisions of the Seibert classifications were needed to assist in selection of appropriate hard tissue augmentation techniques. Wang and Al-Shammari (2002) developed the HVC ridge deficiency classification to address some of the shortcomings of the Seibert (1985) classification. The classification utilizes three general categories to describe horizontal (H), vertical (V), and combination (C) alveolar ridge defects. These three categories can be further divided into the subcategories of small (s, <3mm), medium (m, 4-6mm), and large (l, ≥7mm). Based on the specific category, subcategory and desired rehabilitation modality (fixed prosthesis or implant), different soft and hard tissue treatment options are presented. For example, an H-s defect can be addressed with ridge expansion, inlay/onlay monocortical grafts, or particulate bone grafting; whereas a C-l defect would require large extraoral block grafts or multiple procedures to correct.

Bone Augmentation and Implant Placement
When dental implant placement is planned, the anatomy and extent of a hard tissue ridge deficiency will determine the amount of ridge augmentation needed and whether augmentation is needed horizontally, vertically or in both dimensions. Depending on the amount of ridge augmentation required, implants can either be placed simultaneously with the grafting procedure (one-stage procedure) or after bone augmentation procedures have been completed (two-stage procedure).

Simultaneous vs. delayed implant placement
A delayed two-staged procedure can be indicated when there are horizontal, vertical or combination defects that result in insufficient bone to achieve primary implant stability or when implant placement would result in a peri-implant osseous defect not amenable to grafting. According to Milinkovic and Cordaro (2014), when the horizontal dimension of the residual bone is <3.5mm a delayed two-stage procedure is recommended. A two-stage approach is also suggested when the residual bone height is < 4mm. When the pre-operative vertical defect is >4.7mm, a delayed two-stage procedure is rec-
ommended with expected linear vertical bone gain of 4.3mm.\textsuperscript{12}

A simultaneous one-stage procedure is utilized when adequate bone volume and alveolar crest height allow for primary stability of the implant.\textsuperscript{13} The amount of bone needed to achieve primary stability can vary based on bone quality, but an alveolar crest height of >5mm has been reported as the minimum vertical dimension needed.\textsuperscript{13} A systematic review on indications for different alveolar bone augmentation procedures by Milinkovic and Cordaro (2014) suggests that if the horizontal ridge dimension exceeds 4mm then a simultaneous one-stage procedure can be recommended. In addition, when the preoperative vertical defect is <4.1mm, a simultaneous one-stage procedure is recommended with expected vertical bone gain of 3.04mm.\textsuperscript{12}

One rationale for the simultaneous one-stage procedure is that both block grafts and particulate grafts with a membrane can experience graft resorption, with reported mean volume reductions in guided bone regeneration and ramus block bone grafting sites of 12.5% and 7.2%, respectively.\textsuperscript{14} Placing the implant simultaneously with bone augmentation in a one-stage procedure shortens the time between ridge augmentation and prosthodontic rehabilitation, and thus potentially reduces the risk of bone resorption.\textsuperscript{14} In contrast, those who advocate the delayed two-stage procedure maintain that it allows the implant to be placed in vascularized vital bone and thus potentially increases the osseointegration of implants as measured by bone-implant contact and implant stability.\textsuperscript{15, 16}

While there remains controversy regarding the preferred surgical protocol, the simultaneous one-stage procedure is often the preferred technique by both clinicians and patients because it reduces surgical time, treatment cost and patient morbidity.\textsuperscript{17} In addition, survival rates of implants placed with single and two-stage procedures have been shown to be comparable, with single-stage implant survival rates ranging 61-100% and two-stage implant survival rates ranging 73-100%.\textsuperscript{13} Thus where possible, it is preferable to perform bone augmentation with simultaneous implant placement.

\textbf{A Novel Bone Augmentation Technique with Simultaneous Implant Placement}

Advances in guided bone regeneration using computer-aided design (CAD) and electron beam melting have resulted in the creation of a novel bone augmentation technique using a custom titanium ridge augmentation matrix (CTRAM).\textsuperscript{18} Recently, in conjunction with the 3D Medical Applications Center, NPDs clinicians have applied the use of CAD technology to produce customized matrices using a zirconia material. The newly developed custom zirconium ridge augmentation matrix (CZRAM) is fabricated using a 5-axis milling machine. In a novel treatment modality, CZRAM scaffolds have been designed for use as a surgical guide to facilitate simultaneous ridge augmentation and guided implant placement.

The combination of CBCT imaging and CAD technology to create a CZRAM from virtual 3D models of the jaw allows for precise pre-surgical planning of the ideal ridge augmentation as well as ideal placement of the implant. This novel technique further reduces intraoperative time through the dual functionality of the matrix as both an augmentation matrix and surgical implant guide.

\textbf{Summary}

Prior to ridge augmentation procedures, the ridge deficiency must be classified to allow for proper assessment of defect type and appropriate reconstructive techniques. If the conditions allow, bone augmentation with simultaneous implant placement presents the preferred method of addressing defects with horizontal and or vertical deficiencies.

\textbf{References}


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