"PASS" Principles for Predictable Bone Regeneration

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Guided bone regeneration (GBR) describes a surgical technique that increases and augments alveolar bone volume in areas designated for future implant placement, or around previously placed implants. The principle of GBR is based on the principles of guided tissue regeneration.[1-4] The principles delineated by Melcher[5] described the need for cell exclusion to enable the healing wound to be populated by cells thought to be more favorable for regeneration. In GBR, the cells that are required to repopulate the wound are primarily osteoblasts. Osteoblasts are responsible for laying down new alveolar bone and for future bone remodeling. By selectively excluding epithelium and connective tissue with the use of bone grafting and barrier materials, bone is "guided" into the desired position. Dahlin *et al*[6] were the first to show that bony defects created in rat mandibles could be successfully closed using guided tissue regeneration procedures.

The success and predictability of GBR have since vastly broadened the applicability of implant therapy. Implants can now be placed in areas of previously deficient bone volume, with success rates reported higher than 95%.[7-11] However, to ensure predictability of this technique, clinical procedures should be based on sound biologic principles. This article outlines the 4 major principles underlying successful GBR (Fig. 1): primary wound closure, angiogenesis, space creation/maintenance, and stability of both the initial blood clot and implant fixture (PASS).

*Guided bone regeneration is a well-established technique used for augmentation of deficient alveolar ridges. Predictable regeneration requires both a high level of technical skill and a thorough understanding of underlying principles of wound healing. This article describes the 4 major biologic principles (*i.e.*, PASS) necessary for predictable bone regeneration: primary wound closure to ensure undisturbed and uninterrupted wound healing, angiogenesis to provide necessary blood supply and undifferentiated mesenchymal cells, space maintenance/creation to facilitate adequate space for bone ingrowth, and stability of wound and implant to induce blood clot formation and uneventful healing events. In addition, a novel flap design and clinical cases using this principle are presented. (Implant Dent 2006;15:8–17)*

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Primary Closure

The 2 basic methods of wound healing are termed healing by primary intention and secondary intention, respectively. In healing by primary intension, the edges of a wound are placed together in virtually the same position they held before the injury. Secondary intention describes healing that occurs when wound edges cannot be closely approximated, resulting in a wound that is slower to heal, requires more collagen remodeling, and is more likely to result in scar formation. Realistically, true healing by primary intention is often difficult to achieve. However, primary wound closure is a fundamental surgical principle for GBR because it creates an environment that is undisturbed/unaltered by outside bacterial or mechanical insult.

Passive closure of wound edges enables the wound to heal with less reepithelialization, collagen formation and remodeling, wound contraction, and overall tissue remodeling. In addition, postoperative discomfort may be reduced as a result of less exposure of underlying connective tissue. Most investigators have advocated the necessity of primary closure following implant placement to ensure predictable GBR outcomes,[7,12-15] while others have disputed its importance.[16,17] Nonetheless, there is a consensus that primary wound coverage should be accomplished whenever possible.

Examining the effect of membrane exposure on bone volume gains highlights the importance of primary wound closure. Machtei[18] performed a metaanalysis to evaluate the effects of membrane exposure on treatment outcomes in guided tissue regeneration and GBR. When looking at guided tissue regeneration cases alone, exposed membranes showed only 0.47 mm less attachment gain compared to membranes that remained submerged. In comparison, membrane exposure seemed to have a significant deleterious effect on bone formation. In cases in which the membrane remained submerged, a mean 3.01 mm of new bone

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