

Special Review: Clinical Round-table

The concept of Screw-Guided Bone Regeneration (S-GBR). Part 1: from sinus-lift to general applications in the resorbed maxilla and mandible

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Submitted June 5th, 2013; accepted after minor corrections on June 25th, 2013.

Abstract

The concept of Guided Bone Regeneration (GBR) is quite old and is now covering a large quantity of techniques and combinations of grafting materials and resorbable or non-resorbable membranes. For the treatment of the resorbed posterior mandible, the efficiency of the GBR concept is relatively difficult to fully validate, as it remains difficult operator-dependent techniques where no consensus on the material combination exists. The terminology used in the literature is quite confusing about these techniques, as it covers in fact many different approaches. In this article, we isolate and describe for the first time one very specific approach named Screw-Guided Bone Regeneration (S-GBR), where the osteosynthesis screws and/or screw implants are used as pillars of the bone regenerative compartments during GBR strategies. We show that this particular version of GBR in fact covers transversally many techniques of bone grafting and regeneration which have in theory very little in common, particularly the posterior mandible lateral ridge augmentation and the simultaneous sinus-lift and implantation. We also describe one new approach of pure S-GBR for the treatment of the resorbed posterior mandible based on a 5-year experience with this technique using L-PRF (Leukocyte- and Platelet-Rich Fibrin) as healing and interposition material.

Keywords. Bone grafting, dental implants, fibrin, Platelet-Rich Plasma, sinus floor augmentation.

1. Conceptual evolutions: from GTR to GBR

The concept of Guided Bone Regeneration (GBR) is relatively old. Historically, it started with the development of the concept of Guided Tissue Regeneration (GTR) in periodontology for the regeneration of periodontal tissues around compromised teeth [1]. The theoretical biological principles of GTR are that proper periodontal healing requires to separate the bone and gingival compartments by the mean of a barrier during the wound

tissue healing [2-4], in order to prevent the migration of non-desirable cells (particularly gingival fibroblasts and other soft tissue cells) into the bone compartment. Indeed, after the treatment of an intrabony periodontal lesion, the quickest cells to grow and colonize the curetted bone cavity are the soft tissue cells, and the creation of a fibrous tissue around the teeth is blocking the needed bone regeneration of this space [1].

Many versions of this GTR concept have been developed, using various forms of barrier membranes (resorbable or non-resorbable) and the curetted periodontal defects can be filled with only a natural blood clot, with harvested autologous bone or with a bone substitute (allograft, xenograft or synthetic materials)[5,6]. The various forms of these techniques are nowadays well documented and a common approach used in periodontal surgery, even if there is a lack of consensus on the ideal filling material and membranes to use.

The concept of GTR was advocated as a general therapeutic concept to be extended to many forms of tissues or situations. However, very quickly after the first development of GTR, the concept of GBR was advocated as a more “bone centered” version of the GTR concept [7]. If GTR was kept as a periodontal treatment concept around teeth, GBR was extended to all bone lesions that require regeneration, particularly for pre-implant surgical bone reconstruction or peri-implant bone regeneration [8-10]. The basic biological principles are the same: to prevent soft tissue invagination and protect the bone regenerative compartment during bone healing from the migration of non-desirable cells.

One of the main practical differences between GBR and GTR was that the volumes of tissue to regenerate with GBR were clearly much larger than the volumes involved in GTR, what deeply changed the technical approaches and materials to use between the 2 techniques. Indeed, extended GBR techniques imply a significant risk of failure because of higher mechanical constraints on the regenerative chamber (particularly related to the extended surgical site and the absence of protecting teeth around the site) and the risk of soft tissue dehiscence around extended surgical flaps.

To reach good and predictable clinical results, many kinds of barrier membranes have been tested for GBR [11]. The use of non-resorbable membranes (titanium mesh, ePTFE - expanded polytetrafluoroethylene membranes, etc) is a quite traditional and pure approach of GBR [12,13], as it allows to have a rigid protection of the regenerative bone chamber and sometimes to perform the bone regeneration with blood as sole grafting material. Unfortunately, these membranes are difficult to use and can bring complications such as soft tissue dehiscence during the healing period and membrane bacterial contamination. In addition, membrane removal during implant placement requires an extensive surgical exposure of the newly formed bone. Resorbable membranes (collagen, polylactic acid, etc) are easier to use and are very frequent nowadays [14-16], but they rarely provide enough protection and stability for the bone grafted material (particularly particulate bone grafting material) and their indications have to be selected carefully. The adequate combination of grafting material, membrane and surgical technique remains an important field of debates and research [17-20].

2. From GBR to S-GBR

The concepts of GBR were in fact applied and included in many other techniques, particularly in the various forms of bone grafting [21], distraction osteogenesis [22], segmental osteotomies [23] and alveolar ridge lateral expansion [24]. Even if these techniques are using their own bone regeneration principles, all are based on the concept of

preparation of a bone regenerative compartment (in general filled with a bone materials) and protection from gingival invagination through the use of membranes.

Many forms of bone grafting procedures were developed in the last years in order to reconstruct alveolar ridges suitable for implantation. Sinus floor augmentations were probably the most described techniques among all, as it represents a very frequent and safe treatment of the posterior maxilla, with the axial [25] or with the lateral approach [26]. In the classical surgical procedure using a lateral approach, the sinus membrane is lifted, the prepared cavity is then filled with a bone material (autologous bone, allograft, xenograft or synthetic)[27] and implants can be placed some months after the maturation and integration of the bone graft [26]. There is a consensus [28-30] that most biocompatible materials are functioning well in sinus floor augmentation procedures (even if each material requires different healing time and offers different histological results)[27,31], but it is often recommended to cover the access lateral window with some barrier (membrane or bone fragment) in order to avoid the soft tissue invagination within the sinus cavity [26]. This recommendation follows the principles of GBR.

The alveolar ridge lateral augmentation procedures are also based on bone grafting with various materials associated with the use of membranes of interposition and protection, and are often following the GBR concepts. A famous technique of lateral augmentation is the combination of deproteinized bovine bone graft and porcine collagen membrane [21,32], but many options exist such as the combination of allograft (in small particles or in bone blocks) with collagen membranes and/or L-PRF (Leukocyte- and Platelet-Rich Fibrin) membranes [33,34]. The use of healing and interposition membranes in this kind of surgery is almost always needed and recommended [35].

Alveolar ridge lateral expansion is also a form of GBR, as this technique requires to split the alveolar ridge and to expand it laterally to gain some bone width prior to implant placement [36]. In this technique also the bone chamber can be grafted with various bone material and must be protected by some barrier membranes of interposition between the bone and the gingival compartments. Simultaneous implant placement is often needed, as the implants serve as space maintainers between the 2 segments of the split alveolar ridge after expansion [24,37].

All these techniques can be performed prior to the implantation surgery – and they were described initially as a pre-implant surgical step for bone reconstruction. However with the recent improvements of implant design and surfaces (and the strong reduction of implant prices)[38], the simultaneous bone reconstruction and implantation is a relatively frequent approach. It started with the traditional GBR itself, where the simultaneous implantation allows to use the implants as tent pegs reinforcing mechanically the resistance of the bone regenerative compartment against parasite constraints [12,14,39,40]. This concept of implants as supporting screws was also extended to sinus floor augmentations [41], alveolar ridge lateral expansions [24] and other applications.

These evolutions of implantation created a new approach of GBR. Implants are screws with improved design and surfaces, and can be considered as optimized large osteosynthesis screws. If these screws are used as tent pegs or supporting regenerative pillars in many surgeries in order to maintain and protect the bone regenerative compartment, then they logically impact the way bone is guided and regenerated. This introduced the concept of Screw-Guided Bone Regeneration (S-GBR).

3. Sinus-lift with simultaneous implantation, the S-GBR illustrated

Extended sinus floor augmentations using the lateral approach with simultaneous implantation became recently a good illustration of the S-GBR concept. Several authors advocated that implants could be placed without risk at the time of the sinus-lift bone graft, as long as it was possible to stabilize them in the residual bone ridge [41-44]. As the consensus raised that most bone grafting materials were efficient in the sinus due to the osteogenic properties of the Schneiderian membrane [27-30], some authors suggested to perform the sinus-lift without grafting material [45-47]: the sinus membrane was lifted and maintained in position by the tips of the implants serving as tent pegs. The space between the residual alveolar bone and the membrane was then filled with a natural blood clot and the implants served as pillars for the mechanical protection and stabilization of the sinus membrane in high position. In general, it was recommended to keep the bone fragment of the lateral sinus window and to replace it in its initial position in order to close the sinus regenerative compartment as a natural interposition GBR barrier to avoid soft tissue invagination. The use of another membrane of interposition was also possible if the fragment was lost or left as the new sinus floor after the membrane lifting.

This approach revealed excellent results and also highlighted more physiological results than the traditional sinus-lift with grafting material. Indeed, the use as blood clot as sole filling material allowed to keep the periosteum of the Schneiderian membrane exactly at the level of the tip of the implants and the final bone regeneration of the cavity was done exactly at the size of the future implants, far from the often excessive and uncontrollable volume of sinus floor graft performed with a traditional filling material. This was particularly useful to avoid obstruction of the sinus meatus or non physiological bone grafted volume that can affect the sinus air circulation.

In order to improve this approach, several articles described and validated the long-term results of the use of L-PRF (Leukocyte- and Platelet-Rich Fibrin) clots and membranes as sole grafting material within the sinus cavity [48,49]. L-PRF (marketed as Intra-Spin L-PRF system, Intra-Lock, Boca-Raton, FL, USA) is a platelet concentrate for surgical use of the PRF subfamilies [50]. After centrifugation of whole blood without anticoagulant, a fibrin clot enriched with platelet, leukocytes and growth factors can be collected for implantation [51]. After collection and compression in the Xpression L-PRF Box (Intra-Lock, Boca-Raton, FL, USA)[52], large and strong fibrin membranes for surgical use can be obtained to improve healing [53,54]. These membranes contain most of the platelets and half of the leukocytes (mostly lymphocytes) of the initial blood sample [51]. They release significant quantities of platelet growth factors (Transforming Growth Factor β 1 TGF β 1, Platelet-Derived Growth Factors PDGFs, Vascular Endothelial Growth Factors VEGF)[55] and other healing proteins (thrombospondin-1, fibronectin, vitronectin) during at least 7 days in vitro [56], and offered strong proliferation and differentiation stimulation on several cell types (osteoblasts, bone mesenchymal stems cells, fibroblasts, etc) in vitro [57,58]. L-PRF can be considered as an optimized blood clot and is therefore an ideal material to replace a natural blood clot within a sinus cavity [35,59]. It is also considered as a resorbable barrier that can be combined with GBR techniques [60].

In this surgical procedure, the sinus membrane was lifted carefully (**Figures 1A to 1C**), and then covered and reinforced with a L-PRF membrane. The implants were placed and their tips were maintaining the Schneiderian membrane with L-PRF membrane in high position. The new sub-sinus cavity was then filled with several L-PRF clots placed directly around the implant (**Figure 1D**). The lateral window was then closed to avoid soft tissue

invagination and the use of L-PRF membranes was reported [48] as a sufficient barrier to fulfill this function in this clinical situation (**Figure 1E**). Six months after surgery, the sinus floor bone was partially regenerated and strong enough to place the implant-supported crown. On the radiographic follow-up, the regenerated volume was not completely mineralized, but the new sinus floor was already stabilized just above the implant tip (**Figure 1F**)[49].

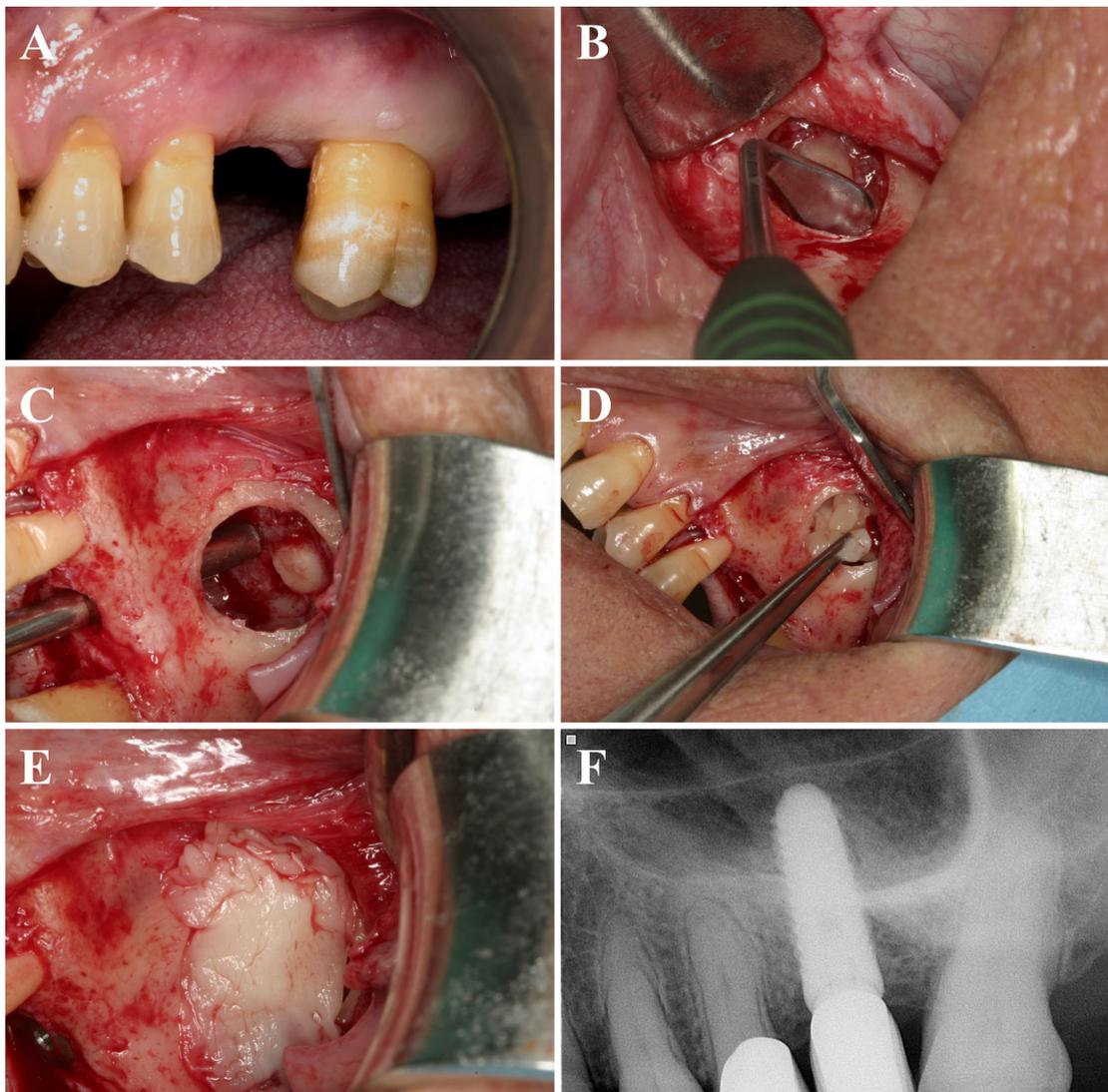


Figure 1. Sinus floor augmentation procedure with simultaneous implantation and L-PRF as sole grafting material. (A) Initial situation. **(B)** The sinus membrane was lifted and the lateral bony window was left in position to serve as new reinforced sinus floor. **(C)** Implant osteotomies were performed and the final step was managed with a manual osteotome. The sinus membrane was covered with a L-PRF membrane and the implant was placed to maintain it in high position. **(D)** The sub-sinus cavity was then filled with four L-PRF clots. **(E)** The lateral window of the sub-sinus regenerative chamber was then covered with 2 L-PRF membranes to protect the compartment and avoid soft tissue invagination. **(F)** Six months after surgery, the implant-supported crown was placed and the radiographic follow-up showed the new sinus floor limit and the bone regeneration on progress of the sub-sinus space.

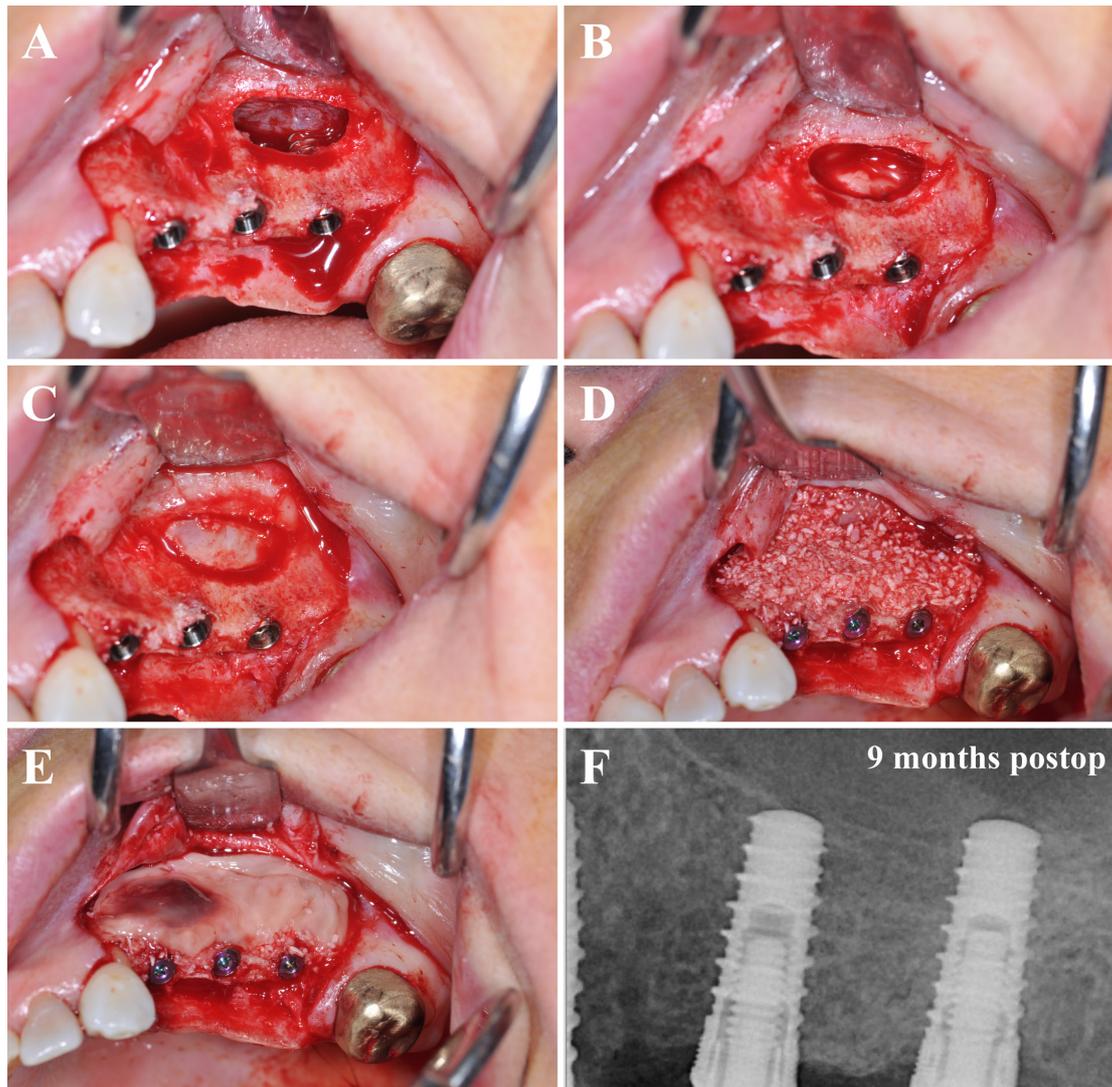


Figure 2. Sinus floor augmentation procedure in the severely resorbed maxilla with simultaneous implantation and L-PRF as sole grafting material, combined with alveolar ridge lateral augmentation. (A) The sinus membrane was lifted after removal of the lateral access bony window, and was covered with 2 L-PRF membranes for healing and protection. Three Ossean implants with micro-threaded collars (Intra-Lock, Boca-Raton, FL, USA) were then blocked in the residual sub-sinus alveolar bone height and their tips served as tent pegs to maintain the sinus membrane and L-PRF membranes in high position as the future sinus floor. (B) The sub-sinus cavity was then filled with 6 L-PRF clots. (C) The sub-sinus cavity was then covered with the initial bone window fragment, as a natural barrier for the regenerative chamber. (D) The area was then grafted with a bone grafting mixture of L-PRF and xenogeneic collagenated bone (Gen-Os, OsteoBiol, Tecness, Italy) following a 50/50 volume mix ratio. (E) The whole surgical site was covered with 2 layers of L-PRF membranes as healing and interposition membranes, and was then sutured. (F) The clinical and radiographic follow-up after 9 months revealed a natural bone regeneration of the sub-sinus cavity.

This L-PRF technique can also be combined with other forms of GBR, such as alveolar ridge lateral augmentation, and gives excellent results on the maxilla [35]. In this case of severely resorbed posterior maxilla, the sinus membrane was lifted, covered with a L-PRF membrane (as protection and healing material) and maintained in high position with the tips of the implants (Figure 2A). Three Ossean implants with micro-threaded collars (Intra-

Lock, Boca-Raton, FL, USA) were used here as the implants needed to be stabilized immediately in the residual sub-sinus alveolar bone height [49]. The sub-sinus cavity was then filled with 6 L-PRF clots (Figure 2B), and closed by replacing in initial position the residual bone fragment of the lateral osteotomy (Figure 2C). The alveolar ridge was then grafted laterally with a mix of L-PRF and bone biomaterial (Figure 2D), and the whole grafted area was covered with 2 layers of L-PRF membranes (Figure 2E) and sutured. Nine months after surgery, the radiographic follow-up showed very well the sinus bone regeneration up to the tips of the implants (Figure 2F).

The cases described above illustrate the advantages of the modified S-GBR approach in comparison to other forms of GBR. In S-GBR, the bone is directly regenerated around the screws serving as tent pegs and space maintainers of the regenerative volume, and this allows to tailor the regenerative volume exactly to what is needed for the success of the treatment. The new sinus floors are always exactly at the tip of the implants [49]. Moreover, as the implant screws serve as pillars for the growth of the implants, we can expect that the process of osseointegration is developing directly on the implant surfaces in the most physiological bone orientation and without the interference of any grafting biomaterial: this is a natural bone chamber model. Following our own experience since 8 years [48,49], we never lost any implants using this form of S-GBR in sinus-lift, even in extremely resorbed maxillary cases. This may be explained by the significant quality of the natural bone regeneration process in this type of surgery. This observation raises new possibilities in many other clinical situations.

4. The new Frontier: pure S-GBR for the reconstruction of the severely resorbed posterior mandible

GBR techniques give excellent results in the maxilla, but the treatment of the severely resorbed posterior mandible remains difficult with this approach. The mandibular bone is very cortical and the integration of a bone grafting material or the regeneration of an implantable bone volume in this area remains a challenge. The literature remains scarce, even if some interesting results of GBR were reported [61]. Many techniques can offer interesting results, but there is no real consensus. Distraction osteogenesis [62,63], segmental osteotomies [23,64] or lateral ridge expansion [24,36] are difficult surgeries and have indications only when the ridge anatomy is compatible. The risk of complications is significant due to the risk of soft tissue dehiscence above the regenerative compartment. The concept of S-GBR with L-PRF seemed therefore an interesting therapeutic strategy.

In this first approach that we started to develop 10 years ago, the S-GBR was mostly applied to the lateral thickening of thin mandibular alveolar crests, in order to rebuild bone width. In this early phase of our technique, we were mostly using a combination of bovine bone, resorbable membranes and non-resorbable membrane with long periods of healing, in order to perform this type of complex bone regeneration. The reconstruction of bone both vertically and horizontally (crestal width and height) is more complicated and requested – from our experience - to use different kinds of materials, particularly bone materials with quicker resorption, integration and turn-over, and the massive use of L-PRF.

This article is the first description of this technique in the literature and this case is an interesting illustration of this type of S-GBR. In early 2007, a 54-year old woman came for the fixed rehabilitation of her left posterior mandible. The second premolar and 2 molars were missing, and the last extraction was done 3 years before, after a history of endodontic

treatment and fracture of the treated teeth. She was wearing a removable denture, and the alveolar bone crest was resorbed and thin. The patient was non-smoker and presented no significant general health problems.

After anesthesia, the surgical site was opened (**Figure 3A**) with full-thickness flaps and it confirmed the dimension of the crest observed on the presurgical radiographs, i.e. 2mm in width in the crestal area, and 12mm high between the top of the crest and mandibular nerve. The bone wall was thin and almost perpendicular with the expected natural occlusion curve. This case was therefore a classical problem of reconstruction of crestal bone width. The buccal face of the crest was first activated with 10 small drills done with a surgical round bur, in order to provoke some bleeding for endosseous stimulation. Then five screws for osteosynthesis (1.5mm in diameter, 8mm long, special kit for implantology, Synthes GmbH, Zuchwil, Switzerland) were placed on this buccal face of the crest with a 90 degrees angle to the crest (**Figure 3B**), in order to maintain the space for the grafted area laterally to this face of the thin alveolar ridge.

The space created between these screws was then filled with a bovine bone substitute (now marketed as CompactBone B, Dentegris GmbH, Duisburg, Germany) using a granulation of 0.5 to 1mm diameter per bone particle. The bone material was placed up to the head of the screws, and the whole area was then covered with a non-resorbable membrane in Teflon (TefGen membrane, Lifecore Biomedical, Chaska, MN, USA) which was adjusted to the surgical site with scissors (**Figure 3C**). This non-resorbable barrier was placed to isolate and protect the graft from the gingival tissue, and was finally covered with a resorbable collagen membrane made from porcine pericardial tissue (now marketed as BoneProtect Membrane, Dentegris GmbH, Duisburg, Germany) in order to help gingival healing and protect the surgical site from eventual gingival dehiscence (**Figure 3D**). This membrane was hydrophilic and quickly soaked with blood, what allowed it to remain well in place. Her resorption time was evaluated between 3 to 4 months. Periosteal incisions on the flaps were performed in order to promote a tension-free closure of the flaps, and the surgical site was sutured with non-resorbable sutures (silk 5.0, Hu-Friedy, Chicago, IL, USA). Sutures were removed after 6 days.

Seven months after the first surgery, the grafted area was healed and presented a strong gingival tissue (**Figure 4A**). The site was reopened, and we observed a quite dense bone (D2 to D3) and no visible resorption around the osteosynthesis screws that were maintaining the space (**Figure 4B**). The 5 screws were removed carefully and the bone holes were bleeding, showing the proper biological integration of the grafted material (**Figure 4C**). Two implants were then placed after careful drilling (TSIII implants, OssTem, Busan, South Korea; 3.5mm and 4.5mm in diameter, 11.5mm long)(**Figure 4D**). The collars of the implants were not completely covered on the buccal face (**Figure 4E**). During the drilling for the implant placement, the bone of the wells was collected and used as grafting material on the collar threads and the head of the implants. A final layer of bovine bone material (CompactBone B) was placed on the surgical site, in order to reinforce the previously grafted volume (**Figure 4F**); the whole area was covered with 4 layers of L-PRF (marketed as Intra-Spin system and the Xpression preparation kit, Intra-Lock, Boca-Raton, FL, USA) in order to protect the grafted volume, to help the gingival healing, to avoid soft tissue dehiscence and to improve the maturation of the gingival tissue around the implants (**Figure 4G**).

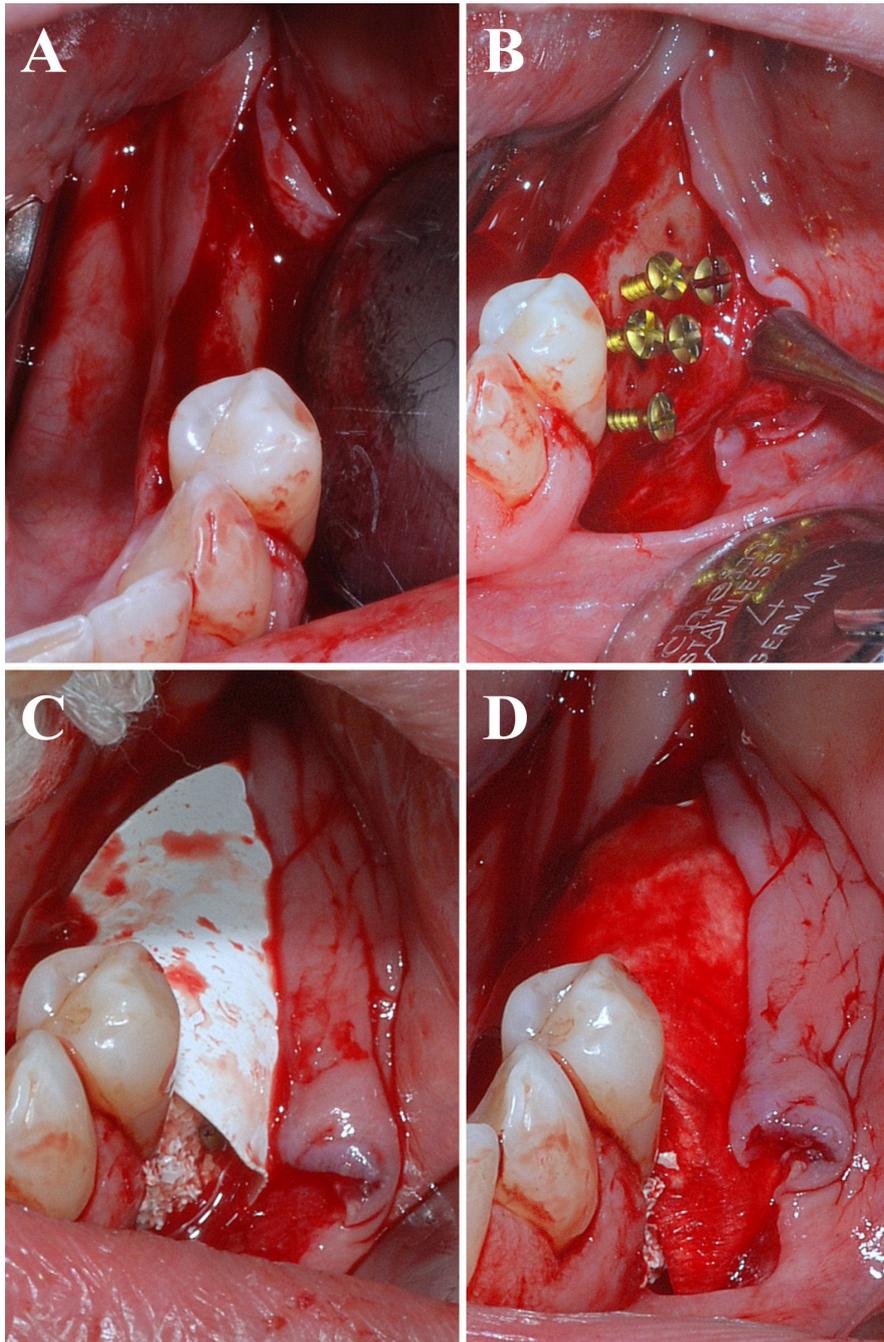


Figure 3. Screw-Guided Bone Regeneration (S-GBR) surgery in the severely resorbed posterior mandible. (A) The residual alveolar ridge was very narrow and could not be implanted directly. **(B)** Five screws for osteosynthesis were placed on the buccal face of the ridge, with a 90 degrees angle to the crest. **(C)** The space created by these screws was then filled with a bovine bone substitute, and the whole area was then covered with a non-resorbable membrane in Teflon, carefully adjusted to the surgical site. **(D)** This barrier was finally covered with a resorbable collagen membrane, to help gingival healing and protect the surgical site. This membrane absorbed blood quickly, and the site was sutured.

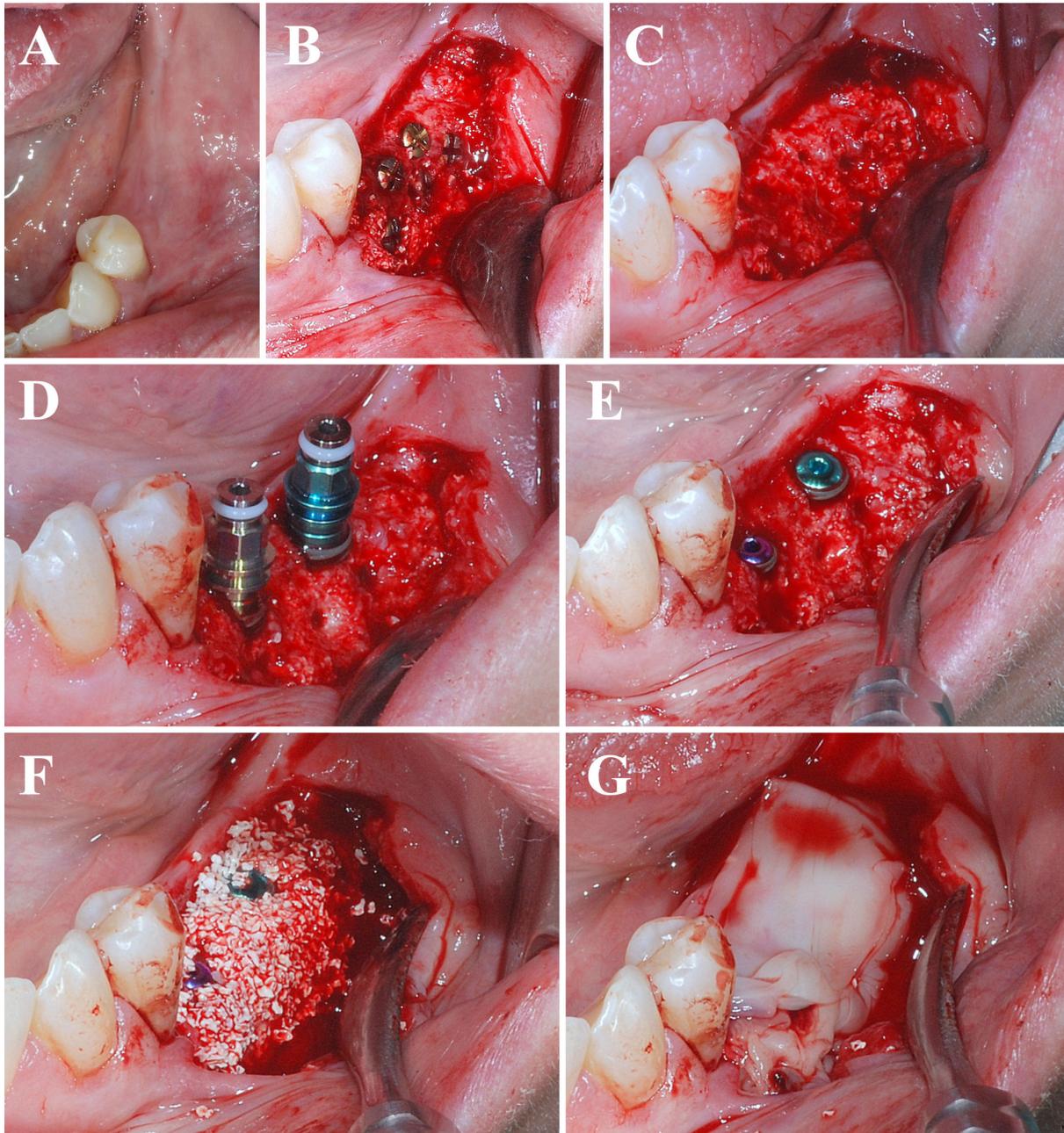


Figure 4. Implant placement and second phase of the S-GBR strategy in the severely resorbed posterior mandible. (A) Seven months after the first surgery, a strong gingival tissue was observed on the healed grafted area. **(B)** The site was reopened and the grafted volume seemed stable and strong around the screws. **(C)** The screws were removed carefully, and we observed some light bleeding from the screw holes. **(D)** Two implants were placed. **(E)** Cover screws were placed and the collars of implants were not completely immersed in bone. **(F)** A bovine bone material graft was added to regenerate more bone on the alveolar ridge around the implants. **(G)** The site was then covered with 4 layers of L-PRF membranes to protect the grafted volume and to help the gingival healing and maturation.

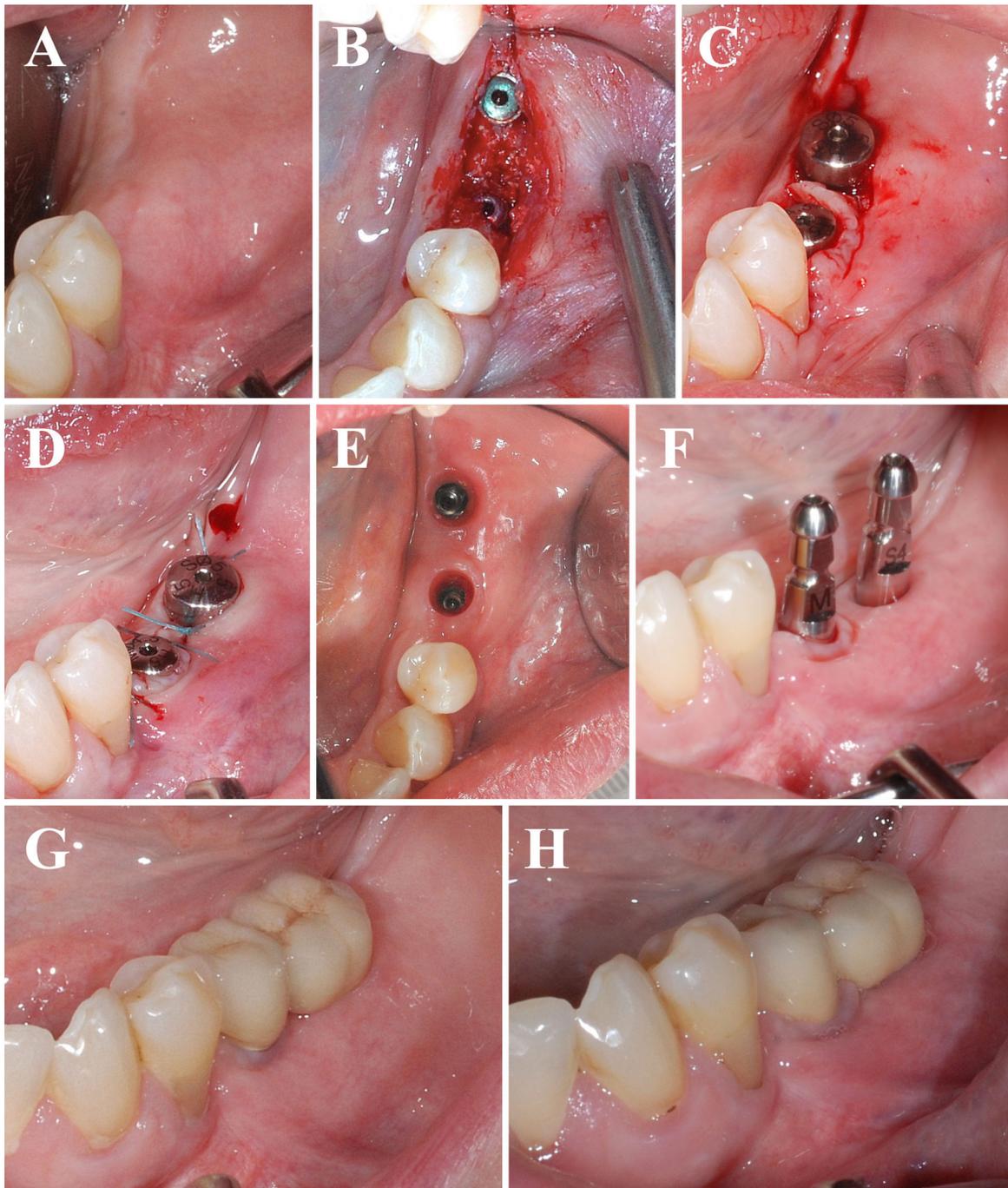


Figure 5. Prosthetic phase of the S-GBR strategy in the severely resorbed posterior mandible. (A) Eight weeks after the implantation, the gingival tissue was healed and mature with the effects of L-PRF, and the implants were ready for loading. (B) Implants were uncovered using a simple incision. (C) Implants were connected to trans-gingival healing screws, and a semi-lunar flap was placed to recreate a papilla. (D) The site was sutured. (E) After 2 weeks of healing, the gingiva was healed and the trans-gingival screws were removed. (F) Impression abutments were placed and impression was performed. (G) Two weeks later, the implant-supported bridge was placed. (H) After a careful 5-year follow-up, the rehabilitation was clearly functional and esthetic, and no bone loss was observed around the implants. We can also observe an increase of the gingival peri-implant covering, probably related to the maturation induced by the use of L-PRF.

Eight weeks after the second surgery, the gingival tissue was healed and the implants were considered ready for loading (**Figure 5A**). The implanted area was opened with a simple incision (**Figure 5B**), and the implants were connected to trans-gingival healing screws. Using a semi-lunar incision, a piece of gingiva was placed between the 2 implants (**Figure 5C**) in order to recreate a papilla [65], and the site was sutured with non-resorbable 5.0 silk sutures (Hu-Friedy, Chicago, IL, USA)(**Figure 5D**). Sutures were removed after 5 days. After 2 weeks of healing, the gingival tissue was healed and the trans-gingival screws were removed (**Figure 5E**). Impression abutments were placed and the impression was taken (**Figure 5F**). Two weeks later, the final implant-supported ceramic-metallic bridge was placed (**Figure 5G**). The patient was then followed up each year with clinical probing and radiographs. Five years after the end of the treatment, the rehabilitation was still functional and esthetic, and no resorption was observed around the implants (**Figure 5H**). It was also observed that the gingival tissue maturation improved year after year, probably induced by the several layers of L-PRF that were used during this therapeutic strategy.

This clinical case presents an early approach of the S-GBR using L-PRF. In this case, the use of the L-PRF was very limited in comparison to all the current potential applications available. However, the treatment of this complex case remains a good illustration of the extension of the S-GBR concept to the most difficult clinical situations, and this approach can open a new Frontier beyond the traditional GBR limitations.

5. Conclusion: GBR, S-GBR or NBR?

This first article illustrates the history of GBR and how the concept of S-GBR arose with its particularities. The S-GBR can be defined as a guided bone regeneration strategy where the bone compartment is protected by a barrier and by screws (osteosynthesis screws and/or screw implants), which serve as strong space maintainers and regenerative pillars. This approach offers new opportunities of treatment, particularly in the severely resorbed posterior mandible.

However, if the use of screws to guide the regeneration is an important parameter, the combination of L-PRF and bone materials opened a new conceptual path. It was advocated that the use of L-PRF with adapted bone substitutes can promote a very physiological bone reconstruction, and this version of the GBR was already termed Natural Bone Regeneration (NBR)[35,59]. NBR and S-GBR are in fact 2 different concepts that need to be associated. The debate is opened and will take several years to be fully clarified and illustrated with the feedback of experience. As a conclusion, terminology is a complex matter, but it should not be neglected as it points out the conceptual differences or similarities between various clinical approaches. Understanding the nuances of techniques remains an important step to improve and develop new techniques.

Disclosure of interests

The authors have no conflict of interest to report.

Acknowledgement

This work for the definition of international standards in implantable materials and techniques is supported by a grant from the National Research Foundation of Korea (NRF) funded by the Korean government-MEST (No. 2011-0030121) and by the LoB5 Foundation for Research, France.

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This article can be cited as:

Toeroek R, Mazor Z, Del Corso M, Dohan Ehrenfest DM. *The concept of Screw-Guided Bone Regeneration (S-GBR). Part 1: from sinus-lift to general applications in the resorbed maxilla and mandible.* **POSEIDO.** 2013;1(2):69-84.