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CLINICAL ARTICLE

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Allogeneic cortical struts and bone granules for challenging alveolar reconstructions: An innovative approach toward an established technique

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Abstract

Objective: The shell technique is a well-established procedure for GBR with which extensive osseous defects can be predictably restored by using cortical bone struts harvested from various intraoral aspects. Recent publications have demonstrated comparable results for autologous and allogeneic bone grafts, whereas the evidence on allogeneic cortical struts remains limited.

Clinical considerations: In this case series, we demonstrate the regeneration of five complex alveolar bone defects in four patients with subsequent insertion of fixed dental implants. In all cases, cortical struts made from human donor bone were applied in combination with allogeneic bone granules and collagen membranes.

Conclusions: Similar to autologous cortical shells, the allogeneic struts functioned by creating an immobile container with which the osseous defects in all patients could be successfully restored, enabling placement of dental implants in accordance with the treatment plan. Even when the containers were solely filled with allogeneic granules, vascularized healthy tissue was present at re-entry, demonstrating the vast potential of these materials for applications in dentistry.

Clinical significance: Especially when it comes to regeneration of complex alveolar bone defects, autologous bone grafts are often outlined as the only treatment modality. Here we show that innovative biomaterials like allogeneic bone grafts hold the potential to mimic the functions of autologous bone transplants and provide excellent clinical results without the requirement of a second surgical side for bone harvesting and no risk of donor-site morbidity.

KEYWORDS

allogeneic bone graft, biomaterials, bone grafting, freeze-dried bone allograft (FDBA), guided bone regeneration (GBR), shell technique

1 | INTRODUCTION

Since the first description by Professor Khoury in 2004, the shell technique has become a widespread and important method for

Robert Würdinger and Phil Donkiewicz contributed equally to this study.

guided bone regeneration in dentistry.[1] The technique makes use of a cortical bone block, which is harvested from the retromolar area near the *linea obliqua*. Unlike other block grafting procedures, this block is then split into thin cortical struts, which are attached to the atrophied jaw by osteosynthesis screws, creating an immobile container which is then filled with autologous bone chips. The cortical bone protects the graft, minimizes resorption within the container and thus, enables the restoration of spacious horizontal and vertical bone defects.[1-4] The detriments of this method are associated with the requirement of autologous bone harvesting: a second surgical site with risk of donor site morbidity and increased pain as well as additional surgical time.[5-7] While patients exhibit a growing desire of having their missing teeth restored with fixed implant-borne prosthetics, as these represent the benchmark in terms of functionality, esthetic appearance and comfort, there is also an request for reduced invasiveness, surgical interventions and surgical burden.[8,9]

In order to obviate bone-harvesting procedures, countless biomaterials for the regeneration of alveolar bone were introduced within the last decades, whereby bovine-based and synthetic bone substitute materials (BSM) have been dominating the European market.[10-12] Although predictable results in several indications were reported for these materials, they are often insufficient for the treatment of complex three-dimensional bone defects and do only function in form of granules, as only few reports about the application of bovine bone blocks limited to sandwich osteotomy and ridge splitting procedures and equine bone blocks with limited clinical success exist.[11-15] So despite these therapeutic improvements, autologous bone transplants still remained the only sufficient option in many instances for example in cases of multiple missing bone walls or large vertical bone defects.[4,16-18] This changed with the commercialization and advancing application of chemically processed human bone transplants, termed allografts, in dentistry. Various authors reported comparable regenerated bone quantity and quality as well as similar survival and success rates of implants placed in the augmented area when evaluating and comparing GBR procedures with allogeneic and autologous bone grafts.[19-21]

Most publications on allogeneic bone grafts focus on their application in form of granules and bone blocks and the comparison of results achieved with autologous grafts.[19-23] While the feasibility of substituting autologous with allogeneic bone blocks has already been presented for a broad range of different alveolar defects, the data available on allogeneic cortical struts for the shell technique is very scarce with only a few reports emphasizing their application for this compelling surgical approach.[20,24-29] With our case series, we seek to demonstrate the excellent clinical performance of allogeneic bone struts and the extended possibilities for regeneration of complex osseous defects they offer. Five defect sites in four patients were successfully restored using allogeneic cortical struts and granules so that additional bone block harvesting was avoided and the patients requests of a less invasive surgical procedure could be met.

2 | CASE PRESENTATION AND SURGICAL PROCEDURE

Four patients with multiple missing teeth and severe bone defects were treated with allogeneic cortical struts, allogeneic bone granules and porcine pericardium membranes. The first case demonstrates a 36-year-old patient who presented with a missing vestibular bone wall and severe horizontal bone loss in the maxilla resulting from extraction of tooth 13, which was carried out *alio loco* (Figure 1A-D). The defect site was projected by preparation of a mucoperiosteal flap via a midcrestal incision followed by a removal of the remaining root fragments of tooth 13 (Figure 1D). The allogeneic cortical strut was split into three fragments which were attached to the jaw by 1.0 mm iron screws; two fragments served as replacement for the missing vestibular wall, while one was attached on the palatal site in order to maintain vertical bone height and increase the stability of the formed container (Figure 1E,F). The space between the allogeneic cortical strut and the native bone was then filled with a 1:1 mixture of cancellous allogeneic bone granules and autologous bone chips, which were harvested in the defect region using a safe scraper (Figure 1G). In order to prevent soft tissue ingrowth while maintaining the volume of the cancellous allogeneic bone granules the defect site was covered with a barrier membrane made from porcine pericardium and closed tension-free by single-button sutures.[29]

Following 4 months of healing, re-entry was performed and the grafted site was uncovered by reopening the initial incision lines. The allogeneic cortical strut was well integrated into the new formed bone tissue and merely visible at re-entry and the grafting volume was well maintained, allowing the insertion of two dental implants according to the treatment plan (Figure 2A,B). A non-resorbable bovine bone substitute was used for relining of the grafted area in order to curb resorption processes and increase the volume stability in the long-term (Figure 2C).[30] The grafted site was again covered with a collagen membrane, which was attached with titanium pins (Figure 2D). Following another 4 months of healing, the implants were uncovered and gingiva formers were installed along with the preparation of a palatal sliding strip flap[31] in order to increase the thickness of attached keratinized gingiva (Figure 2E, F, G). After 3 months of healing, the final dental crowns were installed alio loco by a general dentist (Figure 2I).

The second case demonstrates a 42-year-old woman who exhibited a single tooth gap in regio 46 and an edentulous space ranging from tooth 32 to 42 with a large horizontal bone defect which resulted from aggressive periodontal disease (Figure 3A-D,H). After explaining the different treatment options, the patient decided to have her missing teeth replaced by a fixed implant-borne dentition and restoration of her missing bone with allogeneic cortical struts and granules to avoid autologous bone harvesting. Both defects were uncovered using a midcrestal incision design with two vertical releasing incisions. In order to span the distance of the large edentulous space, two allogeneic cortical struts were required and attached to the jaw using 1.0 mm iron screws (Figure 3E), while one cortical strut was sufficient to create a container for the single tooth gap in regio

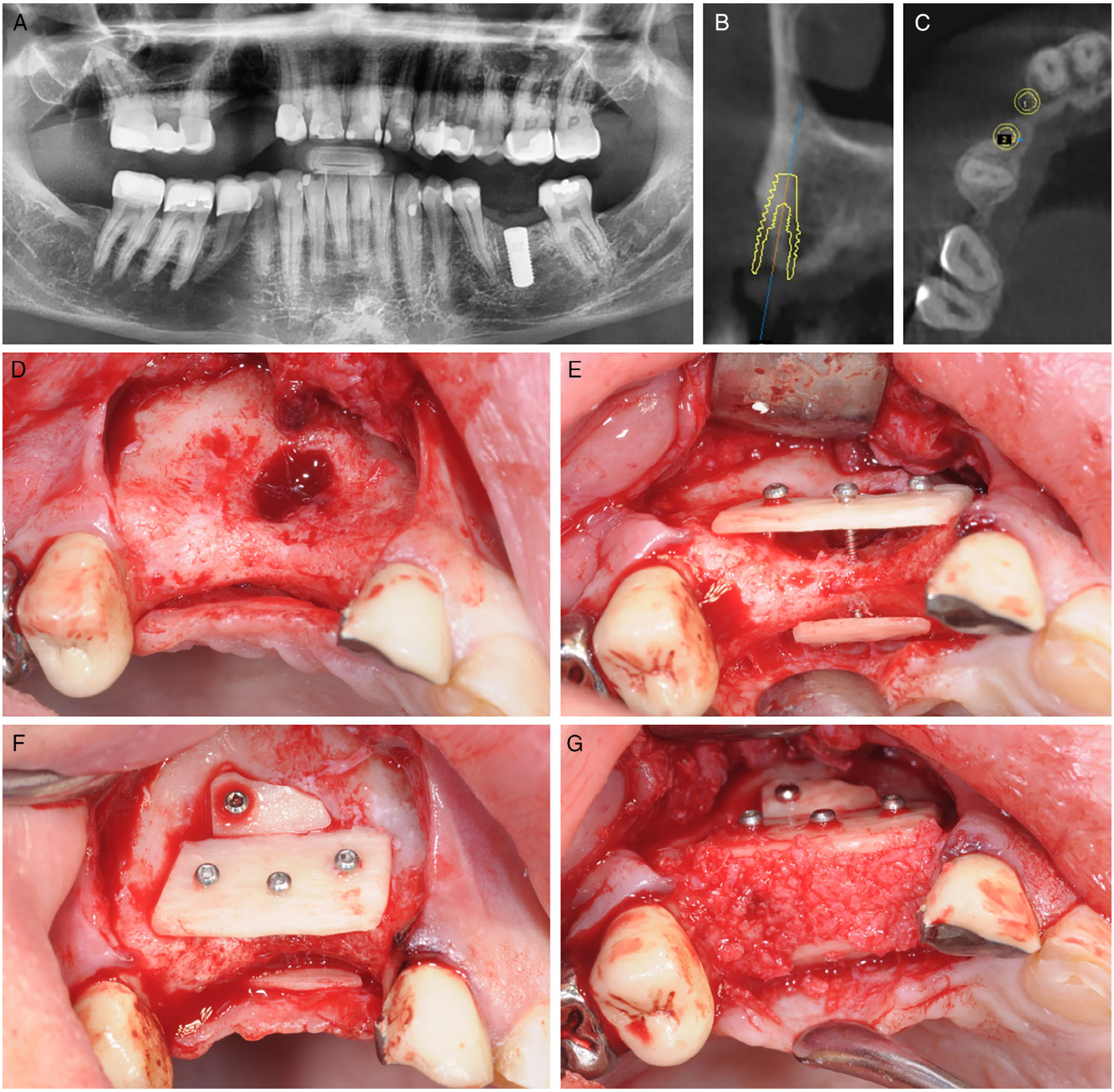

FIGURE 1 A-C, Radiographic evaluation of the defect and implant planning in regio 13. D, Uncovering of the defect site demonstrates an extensive horizontal bone defect with a slight vertical proportion. E, Attachment of the allogeneic cortical strut, which was fragmented into 3 pieces. G, Filling of the container using a mixture of cancellous allogeneic bone granules and autologous bone

46 (Figure 3K). As the bone defect in regio 46 was associated with a large vertical bone loss of tooth 47 which lead to mesial root exposure, a curettage and ultrasonic instrumentation was performed to condition the root surface and allow subsequent application of an EDTA-gel (Figure 3I) for the removal of plaque and remaining proteins from the root's surface in order to allow binding of amelogenin proteins to the root and promote periodontal tissue regeneration (Figure 3J).[32-34] Both defect sites were filled solely with corticocancellous allogeneic granules, covered with collagen membranes and sutured free of tension (Figure 3F,G,K,L).

Following 4 months of healing, insertion of three dental implants in regio 46, 32 and 42 in ideal prosthetic position was successfully conducted (Figure 4B,C). Formation of new, well-vascularized bone tissue was observable adjacent to the root of tooth 37 as well as inside and even outside the container spanning from tooth 32 to 42 (Figure 4A,C). A deproteinized bovine bone material was used for relining of the augmented area 32 to 42 in order to prevent graft resorption. Another 4 months later, the implants were uncovered by stab incisions in order to install a single crown in regio 46 and a fixed bridge spanning regio 32 to 42 with an esthetic overall appearance

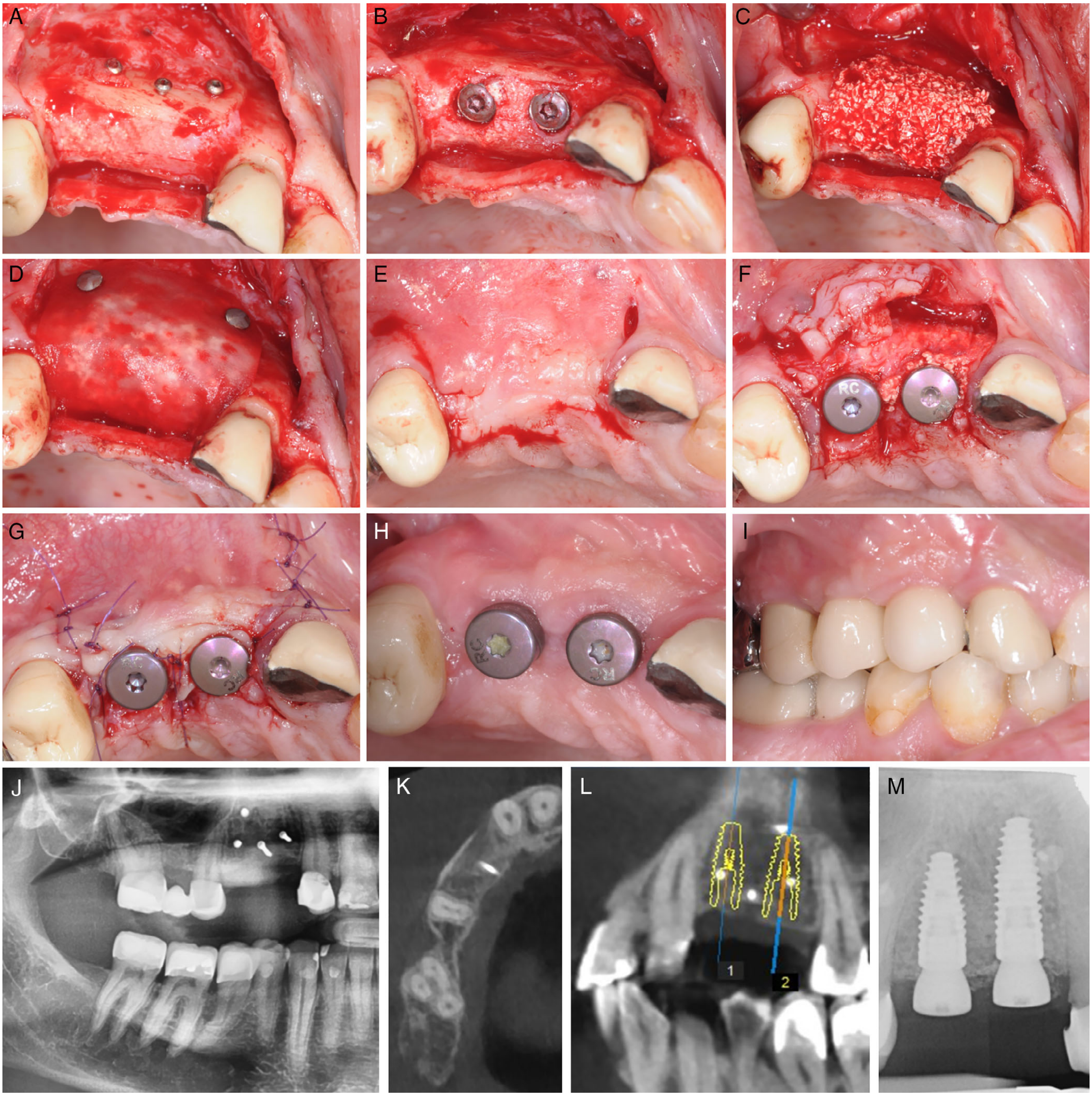

FIGURE 2 A,B, Uncovering of the grafted area and insertion of two dental implants. C,E, Delayed relining technique using xenogenic bone granules and graft covering with a porcine collagen membrane. G,H, Implant uncovering and application of gingiva formers with preparation of a palatal sliding strip flap. I, Excellent soft tissue situation after 3 months of healing and final dental crowns. J, Radiographic assessment of the defect site after grafting. K,L, CBCT control and implant planning before re-entry. M, Radiographic control 4 months after implantation

(Figure 4G-I). Radiographic controls showed no desmodontal space formation mesially of tooth 47 eight months after augmentation and no loss of bone volume in the augmented areas (Figure 4 F).

The third depicted patient is a 57-year old man who underwent extraction of an ankylosed tooth 45 and presented with teeth 46 and 47 not worth preserving. Extraction of the two molars resulted in a pronounced bone defect with about 10 mm of bone missing vertically and horizontally (Figure 5D,E). Despite the complex soft tissue situation, which resulted from a flat base of the mouth, the patient asked for a fixed dental restoration and bone augmentation with allogeneic cortical plates. The defect site was uncovered using a crestal incision line with two vertical releasing incisions. Since the bone deficit was about 10 mm in horizontal and vertical dimension, two allogeneic cortical plates were applied to replace the buccal and lingual bone wall with two outer fixation screws attaching the buccal plate to the jaw and two inner screws holding the lingual plate (Figure 5A,D).

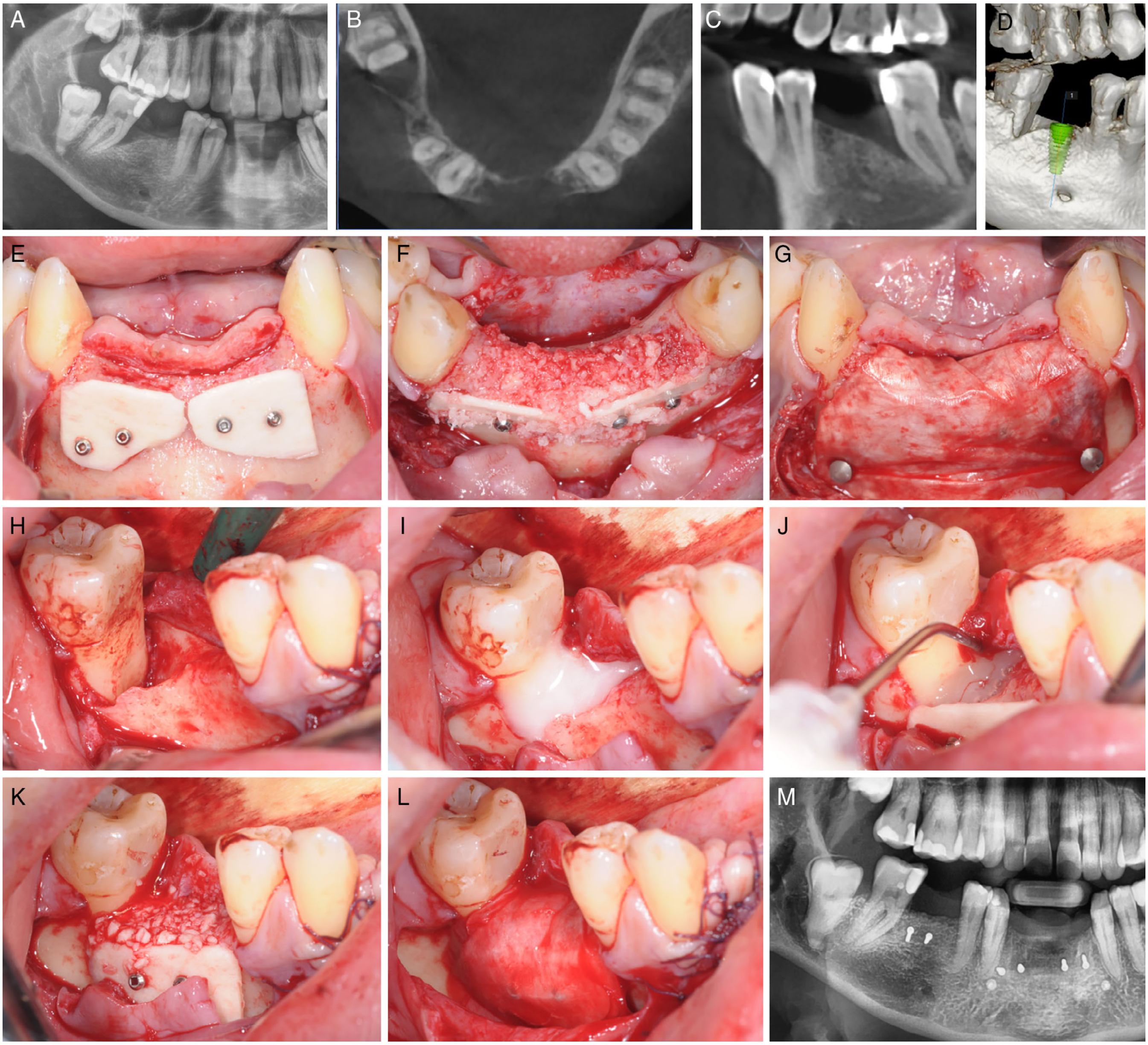

FIGURE 3 A-D, Radiographic evaluation of the bone defects in the lower jaw and implant planning. E,K, Attachment of the allogeneic cortical struts with iron screws. F,G,L, Defect-fill with cortico-cancellous allogeneic bone granules and defect covering with collagen membranes. I, Application of an EDTA-gel for root conditioning and J, subsequent application of porcine amelogenins. M, Radiographic control recorded after augmentation procedure

The space between the two cortical plates was filled with a mixture of allogeneic and autologous bone granules (Figure 5D,E). Periosteal releasing incisions on the buccal site and blunt separation of the *musculus mylohyoideus* from the attached mucosa was conducted in order to mobilize enough soft tissue for coverage of the graft and a radiographic control image was recorded after wound closure (Figure 5G).

Guided implant surgery was performed after 5 months of healing with two implants placed in region 46 and 47 (Figure 6E). The regenerated bone within the augmentation site almost achieved the height of the attachment level of tooth 44 and vital bone overgrowing the buccal site of the cortical plate was also visible in this case (Figure 6C). Due to the extensive defect height of 10 mm and a crestal incision design, minor bone resorption occurred in the center of the grafted area (Figure 6D). After implantation, the grafted site was covered with a bovine bone substitute to prevent bone loss in those areas void of mechanical load. The implants were uncovered by stabbing incisions 4 months later and a modified Kazanijan vestibuloplasty[35] was performed to create attached mucosa around the implant neck (Figure 6G). The final prosthesis was installed 8 weeks later and showed a natural and esthetic appearance (Figure 6H,I).

Following a successful augmentation with allogeneic cortical shells in the lower jaw, the fourth patient, a 70-year old male, presented with massive vestibular bone loss resulting in a vertical bone defect in the

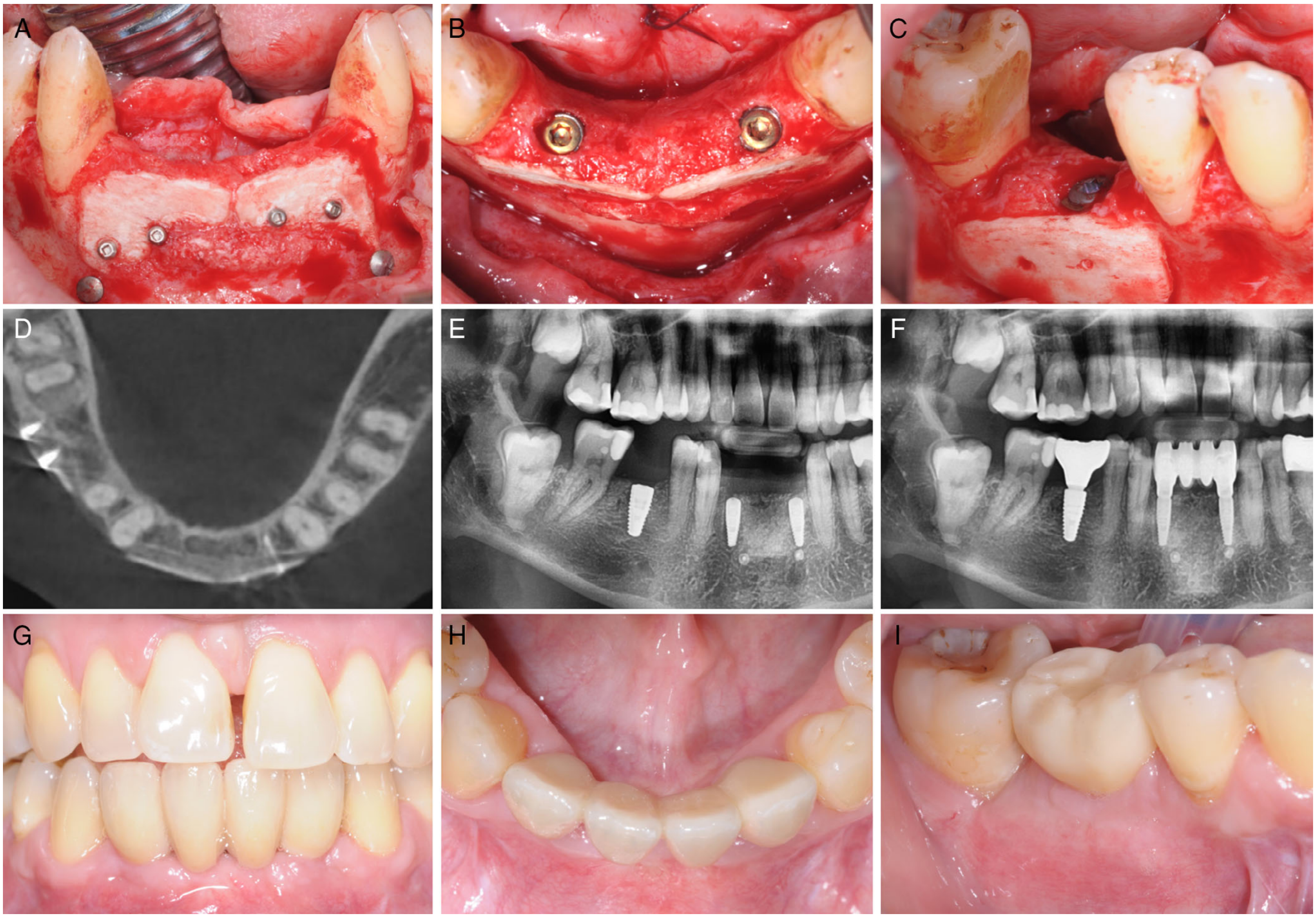

FIGURE 4 A-C, Situation at re-entry 4 months after bone augmentation demonstrates well-vascularized bone tissue. B,C, Successful implant insertion according to the treatment plan was feasible in both augmented sites. D, CBCT control image before implantation shows dense tissue within the container. E, Radiographic control images recorded before implantation and F, after final dental restoration 4 months after implantation. G-I, Final situation with prosthetics

maxilla ten weeks after extraction of tooth 27 (Figure 7A,B). In order to enable insertion of two dental implants, an elevation of the sinus floor using a bovine bone substitute material was planned. Under general anesthesia, a crestal incision from regio 25 to regio 27 with two vertical releasing incisions was performed to access the sinus (Figure 7C). Due to the low bone quality and the pronounced vertical bone loss, an allogeneic cortical shell was mounted to the vestibular wall using two osteosynthesis screws and the container was filled with cancellous allogeneic particles mixed with autologous bone from the maxillary sinus wall, covered with a resorbable collagen membrane and single button- combined with horizontal mattress-sutures were applied for soft tissue closure (Figure 7C,D).

Optimal bone conditions were present after 4 months of healing allowing insertion of two dental implants in regio 25 and 27 to install the planned implant-borne dental bridge (Figure 7E). The implant uncovering was conducted another 4 months later in combination with an apically advanced flap for creation of additional keratinized gingiva (Figure 7F,G). The final prosthetics in the upper and lower jaw were installed 2 months after implant uncovering (Figure 7H). Radiographic control of the implantation sites 9 months after implant insertion demonstrates ideal crestal bone levels without a hint of bone resorption (Figure 7I,J).

3 | DISCUSSION

Regeneration of defects spanning multiple teeth are challenging and require invasive procedures like intra- or extraoral harvesting of bone, which implies a second surgical site and additional burden for the patient.[5,6,17,18] Although autologous bone grafts are considered the gold standard for extensive bone augmentation procedures, the applicability of alternative materials introduced into oral bone regeneration dramatically broadens our portfolio of augmentation techniques with which autologous bone harvesting can be avoided.[19,20,25] Several studies have reported successful and predictable results obtained with bone substitute materials, however in many cases limited to horizontal bone defects.[10-12] Especially cancellous bone blocks made of freeze-dried bone allograft demonstrated comparable clinical results to cortical autologous bone blocks in certain indications.[26] A recent publication demonstrated the full conversion of cancellous allogeneic into

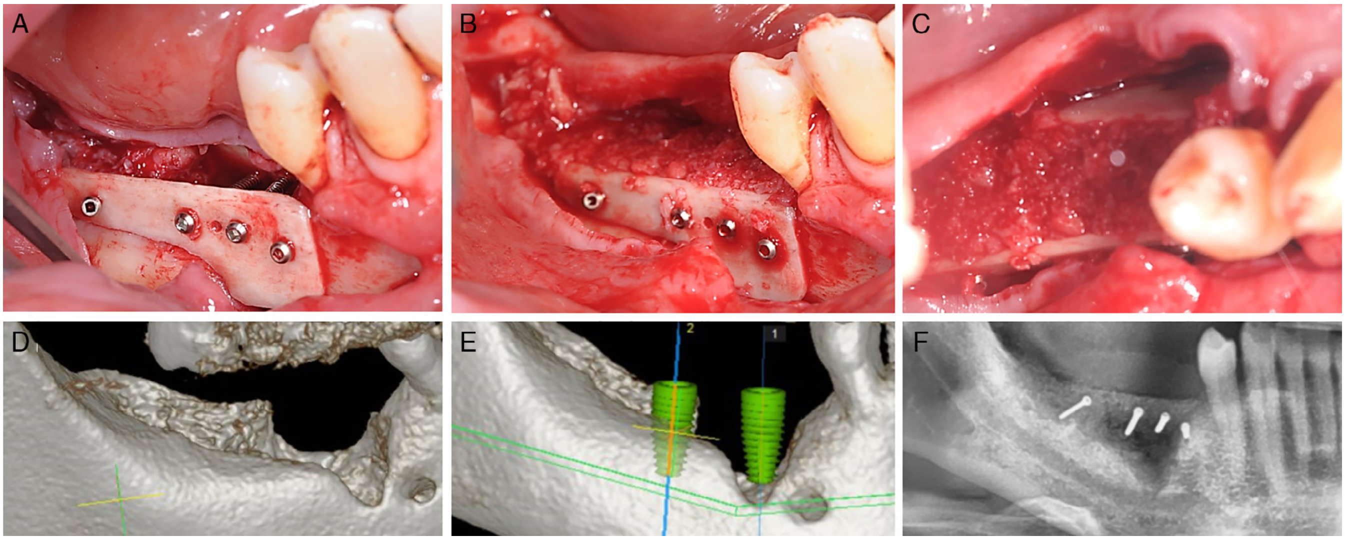

FIGURE 5 Crestal incision design with vertical releasing incisions were placed to access the defect site. A, Two allogeneic cortical struts were fixated on the buccal and lingual site using four 1.0 mm steel screws. B,C, The created envelope was filled with a mixture of autologous and allogeneic bone chips. D, Digital demonstration of the osseous defect and E, implant planning. G, Saliva-tight soft-tissue closure was achieved by periosteal releasing incisions and elevation of mucosal tissue by its separation from the *musculus mylohyoideus* and a radiographic control image was recorded after augmentation

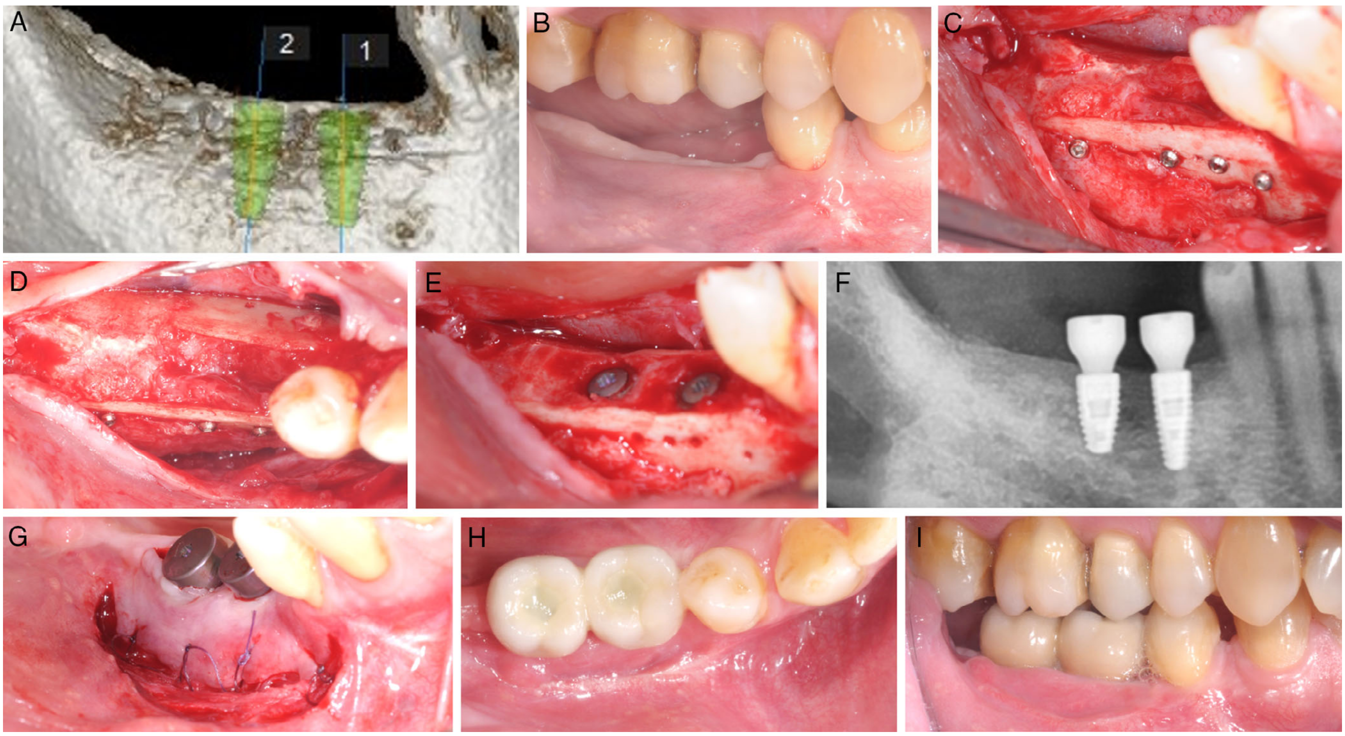

FIGURE 6 A, CBCT-Scan with planned implants 5 months after augmentation. B, Healthy soft tissue situation before re-entry. C, D, Uncovered augmentation site with bone overgrowing the outside contour of the cortical plate. E, Insertion of two implants in regio 46 and 47. G, Kazanijan vestibuloplasty 4 months after augmentation and F, radiographic control. H,I, Final situation with definitive prosthesis

autologous bone by a bone core biopsy retrieved 5 years after augmentation.[36] In addition, several studies have reported high survival rates of implants placed in alveolar ridges augmented with allogeneic bone[20,21,37,38] and bone defects raging from sinus floor elevation to reconstructions of alveolar clefts have successfully been restored with allogeneic bone grafts.[24-28,39]

The high success rate and reliability of autologous cortical shells filled with autologous bone particles even in extensive bone

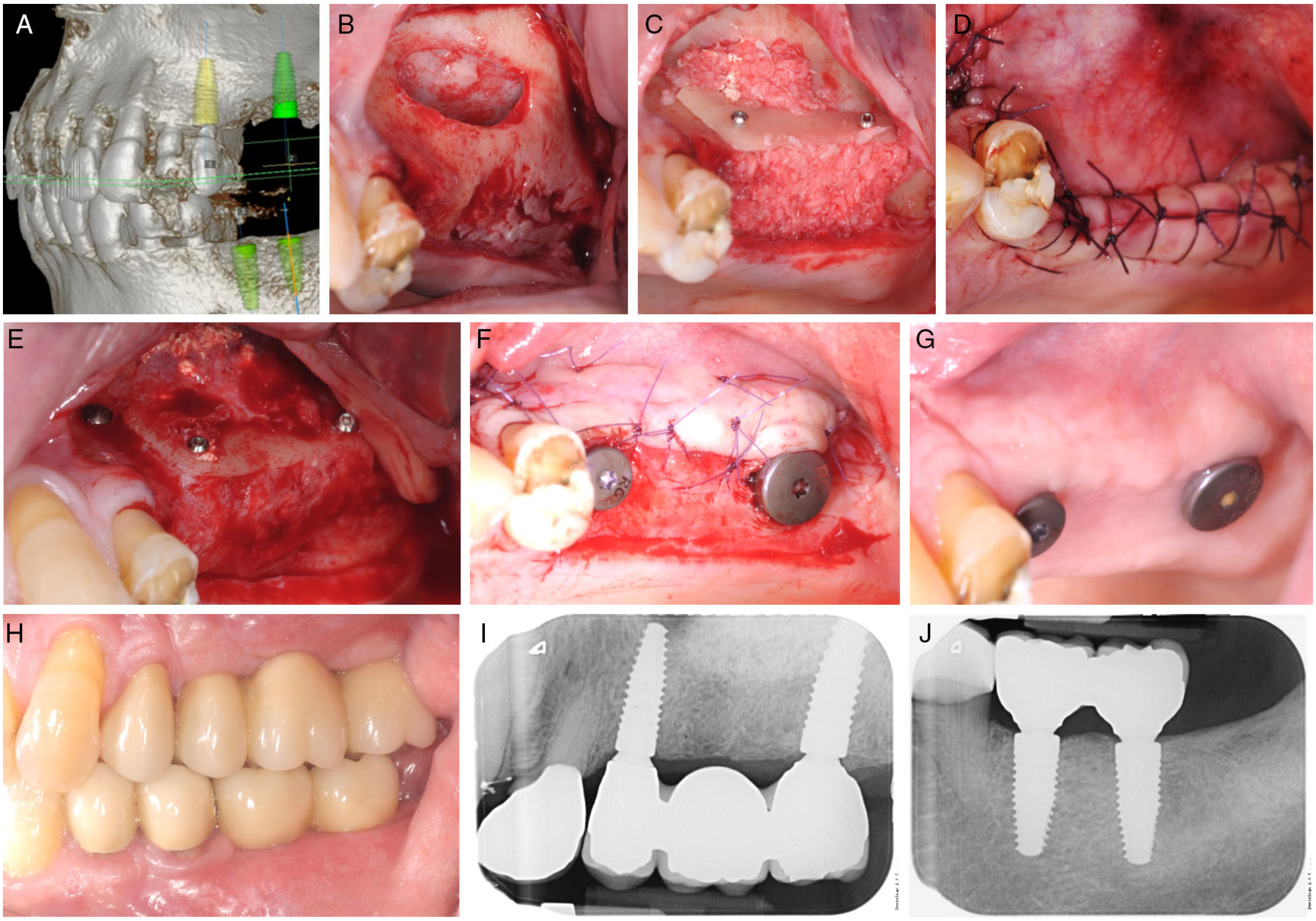

FIGURE 7 A, CBCT-scan of the jaw. B, Uncovering of the augmentation site. C, Sinus-floor elevation with bovine bone substitute material and allogeneic cortical shell augmentation. D, Single-button and horizontal mattress sutures for surgical-site closure. E, Re-entry and dental implant insertion 4 months after augmentation. F, Augmentation of the keratinized gingiva using an apically advanced flap. G, Outcome after 4 weeks of healing. H, Final prosthetics with two single tooth crowns in the augmented lower jar and a bridge construction in regio 25 to 27. I,J, X-ray control 9 months after implantation

regeneration procedures including vertical bone defects is well documented.[1-4,30] One very prominent study by Professor Khoury and colleagues published in 2019 demonstrated 98.8% 10-year implant survival rate for implants placed in jaws augmented with the shell technique.[4] The evidence on allogeneic cortical shells, however, is very scarce and to the best of our knowledge limited to one case series with 10 patient and one case report.[27,28] Furthermore, there are no publications describing the combination of allogeneic cortical shells with other BSM like particulate allogeneic bone. The here presented cases do emphasize that allogeneic cortical shells might be a valid alternative to autologous bone transplants and hence, enable complex bone augmentations without the necessity of bone harvesting. The similar biochemical composition of the allogeneic cortical plate to its autologous counterpart is likely one crucial reason for the excellent results obtained in the here presented cases.

Prosthetic rehabilitation was feasible in all patients without any compromises regarding function and esthetics. The wish of avoiding intraoral bone block harvesting and the risk of donor site morbidity of all patients could be met by the application of allogeneic cortical struts. The vast remodeling potential of allogeneic bone chips was recently demonstrated by Wen and colleagues.[40] They found 41% new bone in extraction sockets preserved with allogeneic granules after 4 months of healing. Regarding the here presented results, the patient solely treated with allogeneic cortical plates and donor bone granules also demonstrated well vascularized tissue without any signs of resorption after 4 months of healing (Figure 4A-C). The application of xenogeneic bone chips after augmentation site uncovering, the so called delayed relining technique, was previously described by Tunkel and de Stavola who demonstrated significant improvement in volume stability maintained by one layer of volume-stable bovine bone covering the augmentation site and was thus implemented in the here demonstrated cases.[30]

4 | CONCLUSION

Allogeneic cortical struts seem to sufficiently mimic the barrier function of autologous cortical plates in alveolar ridge augmentations conducted with the shell technique. Despite complex and extensive ridge defects, excellent results and adequate bone quantity for installation of dental implants was found in all patients. Although this case series is limited in number and controlled trials are needed to draw definitive conclusions about the clinical performance of allogeneic cortical plates, the here presented results emphasize them to demonstrate a valid alternative to autologous bone transplants.

DISCLOSURE

Dr Robert Würdinger is active as a speaker for the Straumann group and receives financial compensations on an honorary basis. Phil Donkiewicz is currently employed as a Key Account Manager for the Straumann Group and simultaneously enrolled as a doctoral student at the Witten/Herdecke University. We received no financial support and no free materials from Straumann or any other company for this work. All surgical procedures were conducted within the regular practice plan. We both confirm that our associations with the Straumann group have no impact on the here demonstrated results.

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