Customized CAD/CAM coral hydroxyapatite block for horizontal ridge augmentation in severe bone defects: A case report

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Received October 16, 2024; Accepted March 28, 2025

DOI: 10.3892/etm.2025.12873

Abstract. Limited data are available on the application of customized bone blocks for horizontal ridge augmentation, particularly those fabricated using coral hydroxyapatite (CHA). The present case report describes a technique for bone augmentation using a customized CHA bone block. The efficacy and clinical feasibility of the technique were evaluated in a 21-year-old man with missing mandibular central incisors and a severe bone defect, with a horizontal bone width of only 2-3 mm. A customized CHA bone block for guided bone regeneration was designed using preoperative cone-beam computed tomography (CBCT) data and computer-aided design and fabricated using a computer-aided manufacturing technique. Following augmentation surgery using the CHA bone block, the soft tissue healed well without dehiscence or infection. After 10 months, CBCT showed that the bone width had increased to 4-8 mm and the implant was inserted. When assessed 7 months later, the value of the implant stability quotient was 70, and the definitive restoration was completed. The customized CHA bone block simplified the surgical procedure, reduced surgical time and minimized postoperative reactions. Therefore, it may serve as a potential alternative to the autogenous bone graft. However, enhancement of the osteoinductive and osteogenic properties of the CHA block would be beneficial, and further studies are required to achieve this.

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Key words: hydroxyapatite, computer-aided design, computer-aided manufacturing, customized, alveolar ridge augmentation, implant, dentistry, oral surgery

Introduction

In patients with severe alveolar ridge resorption and inadequate residual bone volume, bone augmentation is necessary before it possible to introduce a dental implant. However, when conventional bone augmentation techniques such as guided bone regeneration (1), lateral bone condensation (2) and bone splitting (3) are unable to achieve adequate bone augmentation for implantation, autogenous bone grafting (1), which is considered the gold standard for bone grafting, is necessary. Despite its effectiveness, autogenous bone grafting presents challenges, including the need for a separate donor site, limited availability, substantial surgical trauma, slow postoperative recovery, rapid bone resorption, potential graft exposure and infection, and the risk of nerve damage (4-6). In addition, the graft shape may not conform to that of the defect area.

Coral hydroxyapatite (CHA) is used as a bone substitute due to its exceptional biocompatibility, osteoconductivity and non-immunogenicity (7). CHA powder has been used extensively for various clinical applications and provides effective bone augmentation (8-10). However, reports on the clinical application of CHA blocks are limited (11,12).

Computer-aided design/computer-aided manufacturing (CAD/CAM) is being increasingly used in dentistry, particularly in the production of dental crowns and restorative frameworks. This technology also has the potential to be applied to the fabrication of customized CHA bone blocks. The present case report describes a patient for whom a customized CHA block for the augmentation of a severe bone defect was fabricated using CAD/CAM. The clinical efficacy of the CHA block was evaluated as an alternative to autogenous bone grafts that avoids the need for a bone donor site and reduces trauma and postoperative reactions.

Case report

Patient. In October 2021, a 21-year-old man presented at The Affiliated Hospital of Qingdao University (Qingdao, China) due to congenitally missing mandibular central incisors. The patient was in good general health and denied any systemic disease or allergies to drugs. Clinical examination

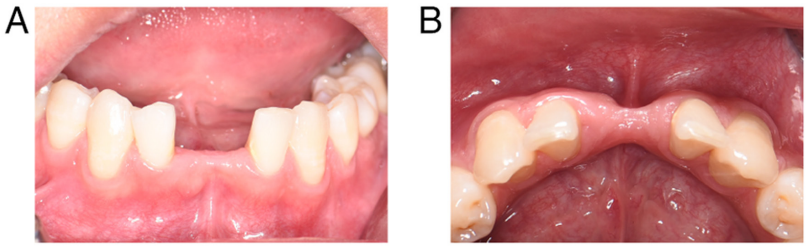

Figure 1. Preoperative clinical presentation of the bone defect. (A) Frontal and (B) occlusal views.

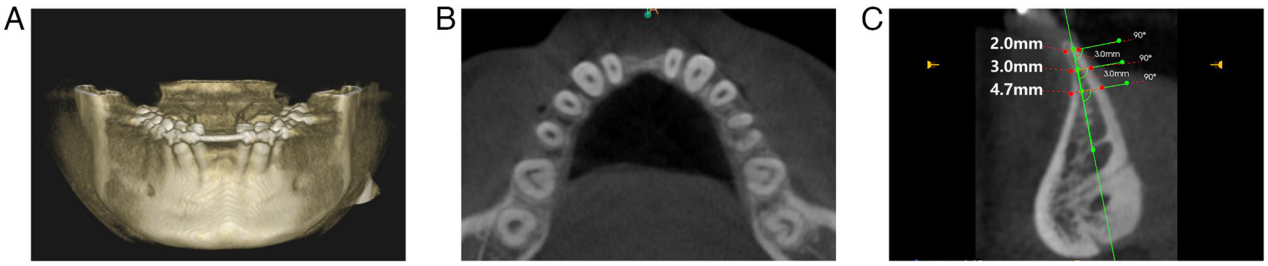

Figure 2. Preoperative bone width assessment by cone-beam computed tomography. (A) Three-dimensional reconstruction, (B) horizontal view and (C) sagittal view.

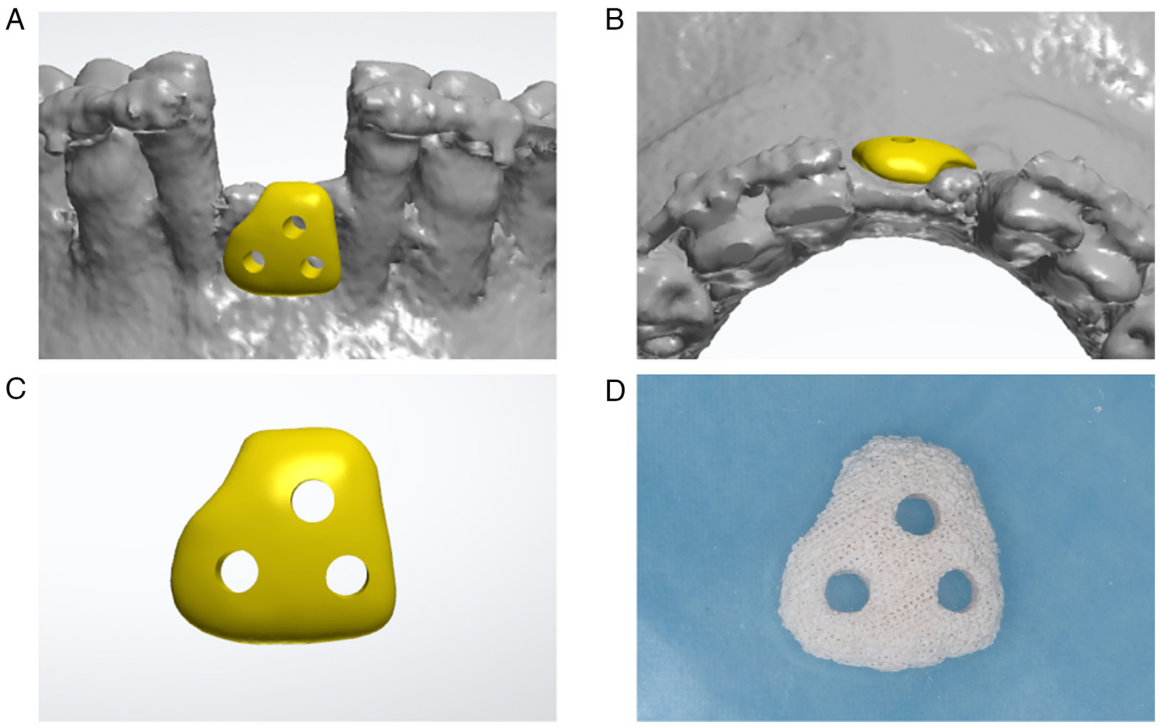

Figure 3. Customized coral hydroxyapatite bone block. (A) Frontal and (B) occlusal views of the block in its intended position and (C) the bone block model in the design software. (D) Photograph of the customized bone block.

revealed missing mandibular central incisors, a significant labial concavity, and adequate keratinized mucosa with a thin gingival biotype (13) (Fig. 1). Cone-beam computed tomography (CBCT) performed using a CS 9300C system (Carestream Health, Inc.) revealed a knife-shaped alveolar ridge with severe buccolingual width deficiency (2-3 mm) and variable height (Fig. 2). The timeline of the clinical procedures is shown in Table I.

Customized CHA bone block. Preoperative CBCT data were exported in a Digital Imaging and Communications in Medicine format, converted to standard tessellation language (STL) using Mimics software (version 20.0; Materialise NV) and then imported into CAD software (3Shape Dental System; version 2021; 3Shape A/S). A digital model of the jaw was reconstructed in the 3Shape Dental System, and a bone block was virtually designed to three-dimensionally fit

Table I. Timeline of the procedures.

Timepoint	Procedure
Before surgery	Preoperative preparation; CBCT and CHA block customization
0 day	Augmentation surgery to introduce the CHA block, immediately followed by CBCT
10 days	Suture removal
6 months	CBCT
10 months	Implant surgery with CBCT before and immediately after
10 months and 10 days	Suture removal
16 months	CBCT and second-stage surgery
17 months	Definitive restoration

CBCT, cone-beam computed tomography; CHA, coral hydroxyapatite.

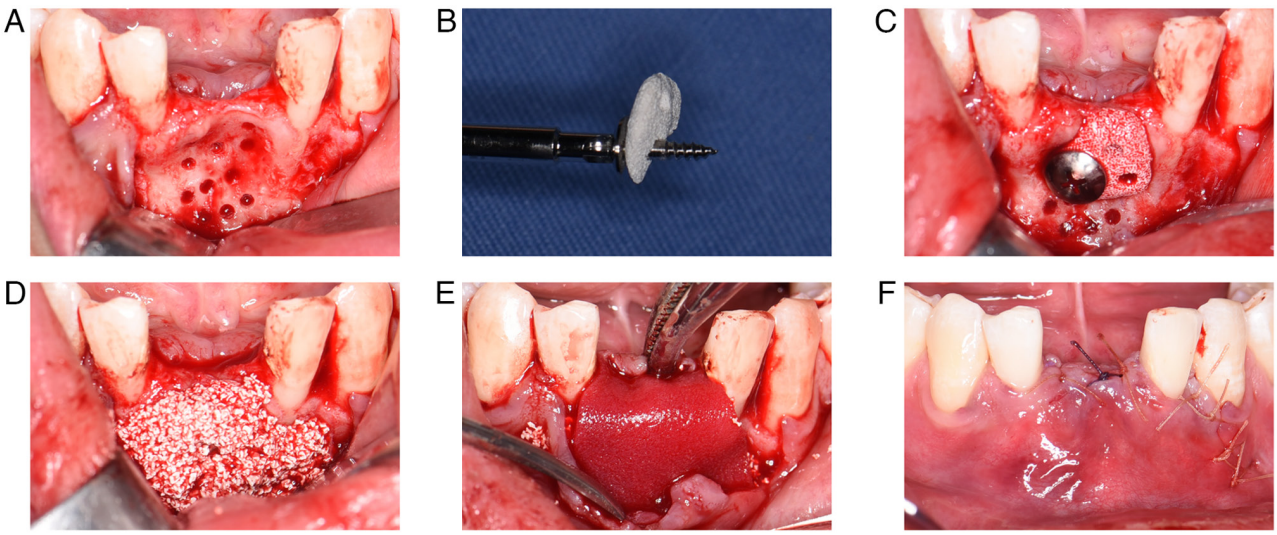

Figure 4. Augmentation surgery. (A) Bone defect with cortical bone perforations. (B) Tenting screw fitted into the pre-designed hole. (C) Bone block fixed with the tenting screw. (D) Bone powder, (E) resorbable membrane and (F) sutured flap covering the block.

the bone defect. Additionally, holes were designed for block fixation. Following finalization of the design, the STL data were exported to a three-dimensional dental milling machine (DWX-4; Roland DG Corporation) in which a raw CHA block (Bio-Osteon; Beijing YHJ Science and Trade Co., Ltd.) was placed. After milling, the customized CHA block was packaged, disinfected and sterilized (Fig. 3).

Augmentation surgery. A midcrestal incision was made under local anesthesia, followed by a vertical-releasing incision mesial to the left mandibular canine. A full-thickness flap was then elevated to adequately expose the surgical site. Multiple cortical bone perforations were performed using a 1-mm round bur to ensure adequate vascularization. The customized CHA block was then placed in the recipient area, and the fit was verified. The tenting screw was screwed into the mandible by passing it through a pre-drilled hole in the CHA block. The diameter of the head of the screw used (~5 mm) was larger than that of a bone screw (~2 mm), which provided greater stability. The CHA block was rigidly fixed to promote blood absorption and integration into the host bone. Residual voids were packed with CHA powder (Bio-Osteon) to compensate for marginal deficiencies and achieve a smooth alveolar contour. The graft was then covered with a resorbable collagen membrane (Heal-All® membrane; Yantai Zhenghai Bio-tech Co., Ltd.), and the flap was sutured under tension-free conditions following periosteal releasing incisions and labial vestibular extension (Fig. 4). The sutures were removed 10 days after augmentation surgery, and wound healing was assessed for any signs of infection or dehiscence. In addition, CBCT was performed immediately after, 6 months after and 10 months after grafting surgery to evaluate the bone volume.

Implant placement. Re-entry was performed 10 months after bone augmentation (Fig. 5). The surgical site was adequately exposed under local anesthesia, the tenting screw was removed and a 3.5x11.5 mm NobelActive® implant (Nobel Biocare AB) was inserted. Guided bone regeneration was then performed using bone powder and resorbable membrane. CBCT was performed immediately after and 6 months after implant placement. The second-stage surgery involving implant exposure and healing abutment placement was performed 6 months

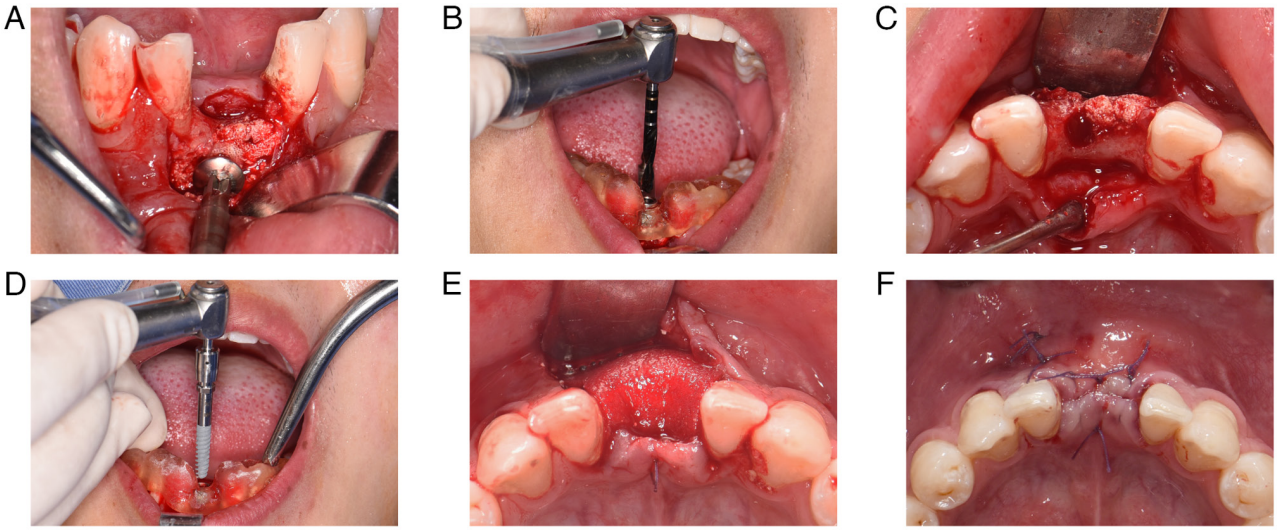

Figure 5. Implant surgery. (A) Removal of the tenting screw. (B-D) Drilling and implant insertion. (E) Bone powder and resorbable membrane covering the implant site and (F) sutured flap.

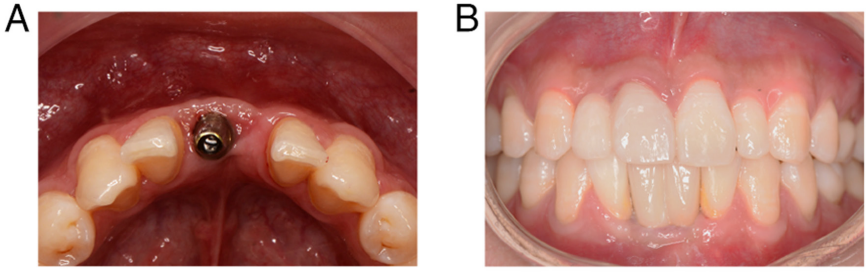

Figure 6. Definitive restoration. (A) Dental implant abutment and (B) crown.

after implant placement, and the definitive restoration was completed with a dental crown placement 1 month after the second-stage surgery (Fig. 6). The implant stability quotient (ISQ) value was tested using an Osstell ISQ device (Osstell AB).

The wound healed well with no signs of tissue dehiscence or infection during follow-up. When assessed 10 months after CHA block grafting, the bone width had increased to 4-8 mm, and the implant was placed with an insertion torque of 35 Ncm. However, some residual CHA granules were observed, and partial detachment of the CHA block was observed labially after osteotomy preparation. The ISQ value was 70 at the time of definitive restoration. The bone volume results are presented in Figs. 7 and 8. The last follow-up date was June 2023 and the patient was satisfied with the clinical outcome of implant-supported restoration.

Discussion

The identification of alternatives to autogenous bone for grafting is essential as, although autogenous bone possesses osteogenesis, osteoconductive and osteoinductive properties, it remains limited by the morbidity associated with harvesting (14). Treatment options considered for the present patient included autogenous bone grafting, titanium mesh with guided bone regeneration, and allogeneic or xenogenic bone block grafting. While a combination of bone powder and a resorbable collagen membrane provides inadequate support and poor stability, the application of a titanium mesh makes the maintenance of space using bone powder feasible (15). Although titanium mesh has certain advantages, it is also associated with a high rate of complications, including early or late exposures, consequent infections, and interference with bone healing due to the soft-tissue layer beneath the titanium mesh (16-18). Allogeneic grafts are typically derived from cadavers, and while other studies have used customized allogeneic bone blocks for augmentation prior to implantation (19-21), biological safety remains a concern due to the potential for disease transmission, immune reactions and ethical considerations (22,23).

In the present case, a customized CHA block was fabricated using natural coral. CHA has a three-dimensional structure with interconnected channels, a porosity of 50-70%, and pore diameter of 200-500 μm; and the porous structure is conducive to bone tissue ingrowth, nutrient transport and waste elimination; furthermore, its osteoconductive potential contributes to CHA being a desirable bone substitute (12). Manual contouring prior to fixation was not necessary since the block was pre-shaped to fit the defect.

The main component of natural coral is calcium carbonate ($CaCO_3$), which can be converted into hydroxyapatite (HA) through a hydrothermal reaction. HA undergoes bioresorption

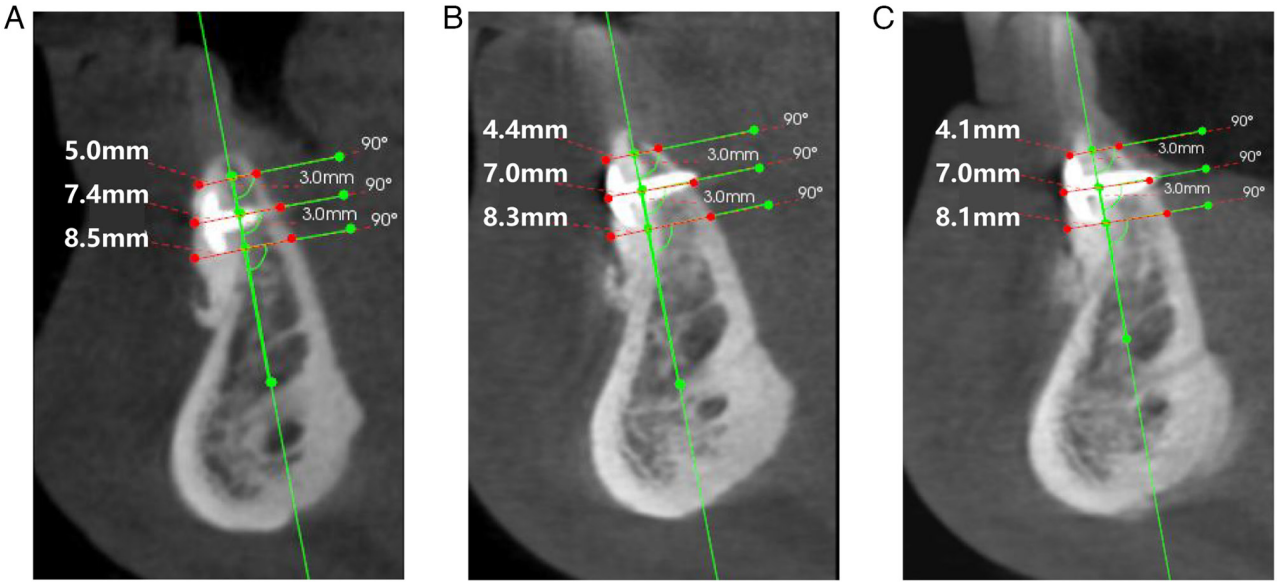

Figure 7. Bone width assessment by cone-beam computed tomography after augmentation surgery. (A) Immediately, (B) 6 months and (C) 10 months after the surgery.

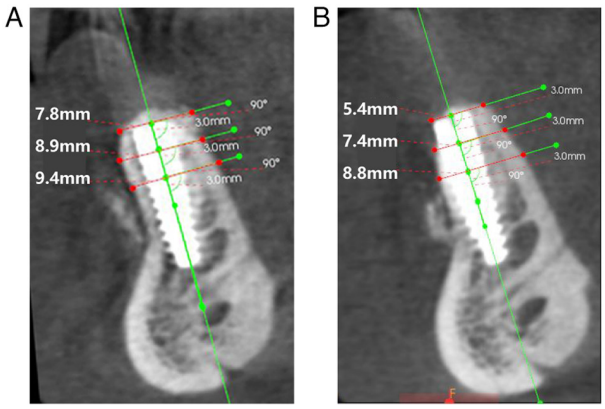

Figure 8. Bone width assessment by cone-beam computed tomography after implant insertion. (A) Immediately and (B) 6 months after implant insertion.

more slowly than $CaCO_3$, which significantly impacts bone remodeling (24). The resorption rate of HA varies between 0 and 5% per year (25). Therefore, regulation of the hydrothermal conversion process enables the degradation rate of the CHA block to be adjusted (26). Therefore, to ensure optimal coordination between CHA degradation and new bone formation rates, the surface layer of coral was transformed into HA, while $CaCO_3$ was retained in the core. However, a healing period of 10 months in the present case indicated relatively slow osteogenesis. Therefore, it is suggested that adjusting the proportion of HA in future applications could help to accelerate bone remodeling. The alveolar ridge width increased from 2-4.7 mm prior to bone augmentation to 4-8 mm after 10 months. This increase in bone width, along with the lack of any signs of tissue dehiscence or infection, demonstrates the safety and feasibility of this technique.

The customized bone block fabricated using CAD/CAM achieved optimal fit with the recipient site, simplified the surgical procedure, eliminated the need for intraoperative bone harvesting and shaping, and reduced surgical time. However, some deviation in fit was inevitable due to factors such as data acquisition, design and manufacturing errors. To compensate for these deviations and ensure a uniform contour, CHA powder was used to fill gaps and margins. Successful bone grafting was achieved through the stable and rigid fixation of the graft to the recipient bed (27), which may be attributed to the customized shape of the block and the use of a tenting screw.

In a previous study, Yao *et al* (11) found that CHA blocks and autogenous bone grafts both effectively restored mandibular height. They successfully placed implants 6 months following a bone augmentation procedure; however, preparation of a box-shaped socket was required for fixation. In a study on the osteoconductivity of CHA blocks in rabbits (12), the blocks dissolved, bony trabeculae thickened and fused with each other, and a small amount of new bone appeared in the center at 8 weeks. By 12 weeks, there was a further increase in the peripheral new bone, characterized by the formation of lamellar bone and bone marrow, as well as increased blood vessel formation and thickened trabeculae in the center. In another study using rabbits (28), histological observations at 8-15 months showed that the CHA block degraded into linear remnants, and the areas of degradation were filled with regenerated bone and some bone trabecula.

Sufficient blood supply is a key factor in osteogenesis, particularly given the lack of osteogenic potential of CHA. Therefore, proper case selection is crucial. The Lekholm and Zarb classification system (type I-IV) is a widely method in dental implantation to assess bone quality: Completely homogeneous cortical bone is classified as type I; dense trabecular bone with thick cortical bone layer is classified as type II; dense trabecular bone with thin cortical bone layer is classified as type III; and porous trabecular bone with thin cortical bone layer is classified as type IV (29). Homogeneous cortical bone has the worst blood supply. In the present patient, the bone was classified as type III, which had dense trabecular bone and met blood supply requirements.

At the 10-month assessment after bone augmentation, the CHA block had not completely degraded or transformed into bone tissue, and some granules remained. Furthermore, a part of the labial CHA block detached after osteotomy preparation. Therefore, secondary bone grafting using CHA powder was performed at the time of implant placement. The definitive restoration was completed after 6 months of healing. The ISQ value can be used to assess implant stability and osseointegration. It ranges from 0 to 100, with 100 representing the highest stability (30,31). The ISQ value was 70 in the present patient at the second-stage surgery, indicating good osseointegration.

Poor mechanical strength and high brittleness are limitations of CHA blocks. A previous study on the physical and mechanical properties of three natural corals reported compressive strengths of 2.62-12.06 MPa; by contrast, the compressive strength of the human femur is 131-283 MPa (32). Therefore, to reduce the possibility of block fragmentation during fixation, a perforation was designed for the fixation screw in the present case. In addition, a screw with a large head was used to increase the retention force of the CHA block.

In the present case, the customized CHA block used for augmentation of a severe bone defect reduced surgical time and postoperative reactions, although secondary bone grafting was necessary. Nonetheless, implant restoration was successful. The customized CHA block may serve as a potential alternative to the autogenous bone graft. However, while CHA is osteoconductive and osteoinductive, it lacks osteogenic potential. Also, it has a slow bone turnover rate, poor mechanical strength and high brittleness. Therefore, further research and modifications are necessary to enhance the mechanical and osteogenic properties of CHA blocks and improve their osteogenic ability. Studies including a larger number of patients and longer follow-ups are required to explore and evaluate the long-term effects of customized CHA blocks. Additionally, it would be interesting to test the present technique in combination with other recently introduced adjunctive treatments that have shown promising results, such as ozone treatment (33), photobiomodulation (34), paraprobiotics (35), platelet-rich plasma or growth factors (25), in order to evaluate their mutual effect on tissue healing.

Acknowledgements

The authors thank Beijing YHJ Science and Trade Co., Ltd. for technical support.

Funding

Support was provided by the Shandong Municipal Health Commission (Project 202208050566), the Qingdao Natural Science Foundation (projects 23-2-1-133-zyyd-jch and 23-2-1-144-zyyd-jch) and the Qingdao Municipal Health Commission (Project 2021-WJZD183).

Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

SJ and WXW interpreted and analyzed the data and drafted the manuscript. CZ and XJL acquired the data and revised the manuscript. XL and BDZ designed the study, conducted the treatment and revised the manuscript. XL and BDZ confirm the authenticity of all the raw data. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

The study was approved by the Ethics Committee of The Affiliated Hospital of Qingdao University (QYFYWZLL27281).

Patient consent for publication

Written informed consent for publication was obtained from the patient.

Competing interests

The authors declare that they have no competing interests.

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