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Prototyped grafting plate for reconstruction of mandibular defects☆

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ABSTRACT

To esthetically and functionally restore a 40-mm canine mandibular discontinuity defect using a custom-made titanium bone-grafting plate in combination with autologous iliac bone grafts. Individualized titanium bone-grafting plates were manufactured using a series of techniques, including reverse engineering, computer aided design, rapid prototyping and titanium casting. A 40-mm discontinuous defect in the right mandibular body was created in 9 hybrid dogs. The defect was restored immediately using the customized plate in combination with autologous cancellous iliac blocks. Sequential radionuclide bone imaging was performed to evaluate the bone metabolism and reconstitution of the grafts. The specimens were evaluated by biomechanical testing, 3-dimensional microcomputed tomographic scanning, and histological examination. The results revealed that the symmetry of the mandibles was reconstructed using the customized grafting plate, and the bony continuity of the mandibles was restored. By 12 weeks after the operation, the cancellous iliac grafts became a hard bone block, which was of comparable strength to native mandibles. A fibrous tissue intermediate was found between the remodelled bone graft and the titanium plate. The results indicate that the prototyped grafting plate can be used to restore mandibular discontinuous defects, and satisfactory aesthetical and functional reconstruction can be achieved.

1. Introduction

Reconstruction of mandibular defects poses a challenge to the head and neck reconstructive surgeon. Alloplastic implants have been used for mandibular reconstruction for a long time, of which the mandibular reconstruction plate is most commonly used. It is indicated in patients with discontinuous mandibular defects. Complications, including hardware extrusion and plate fracture, occur in the long term and secondary salvage reconstruction with a vascularized osteocutaneous free flap is often needed. The focus of mandibular reconstruction has now shifted to optimizing functional and aesthetic outcomes and microvascular reconstruction with osseous free tissue transfer has become the preferred technique for mandibular reconstruction. This type of reconstruction also requires rigid internal fixation with plates and screws at osteotomy sites. During the clinical application of the plates, especially for the mandibular reconstruction plate, surgeons have found that it is challenging to form a perfect shape to fit for the residual mandible with plate shaping time consuming and requiring great effort, making it difficult to reconstruct ideal facial contour.

By employing the reverse engineering (RE), computer aided design (CAD) and rapid prototyping (RP) techniques, individualized endoprosthesis can be manufactured for difficult mandibular defects to achieve restoration of satisfactory facial contour (Zhou et al., 2010, 2011; Eufinger et al., 1997; Stojadinovic et al., 1999; Singare et al., 2004). Mandibular bony continuity can be reconstructed when combining the individualized endoprosthesis with autologous bone grafting techniques, including vascularized or non-vascularized osseous free flaps.

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In this study, we designed a customized bone grafting plate for reconstruction of mandibular defects, using the RE-CAD-RP technology. A 40-mm defect on the mandibular body of 9 hybrid dogs was restored using the customized plate in combination with autologous iliac grafts.

2. Material and methods

Nine hybrid dogs, aged 12–18 months and weighing 13–15 kg, were used in this study. The animals were housed and cared for in accordance with the guidelines of the Laboratory Animal Centre of the Fourth Military Medical University. This study was approved by the Animal Care and Use Committee of Fourth Military Medical University.

2.1. Design and fabrication of the grafting plate

Under general anaesthesia with an intramuscular injection of Sumianxin II 0.1 ml/kg (Huamu Animal Health Product Co. Ltd, Jilin Province, China), the right mandibles had the posterior teeth removed, leaving the canine teeth and all incisors. Two weeks later, helical CT scanning (GE BrightSpeed Elite 16 Slice CT scanner, 120 kV, 240 mA, GE Healthcare, Waukesha, WI, USA) was performed under general anaesthesia, with 1.25-mm slice thickness, and the CT data of the skull of each subject were imported into Mimics 11.0 (Materialise NV, Belgium) to reconstruct the 3-dimentional digital model of the jaw. Virtual mandible resection (40 mm) was performed on the digital model using the software Geomagic Studio 6.0 (Raindrop Geomagic, Research Triangle Park, NC, USA). A custom grafting plate was then designed to repair the defect. To design the plate, the intact left mandible was mirrored to match the missing segment of the right mandible. The sagittal plane between the 2 central incisors and the condyles was taken as the mirror plane. The grafting plate was designed based on the buccal surface of the mirrored mandible. The inferior border of plate equated to the inferior border of the mandible, while the superior border was 2–3 mm lower than the alveolar ridge crest. The plate extended onto the inferior surface of the mandibular body. An extended footplate was designed at both ends to allow the grafting plate to be fixed to the adjacent residual bone. A solid model of the grafting plate was created by thickening the surface of the plate 0.8 mm, outwards. The virtual model was converted to a stereolithography (STL) file format. The digital grafting plate was manufactured in the LPS 600 (laser prototyping system; Xi'an Jiaotong University, Xi'an, Shaanxi, China) stereolithographic system. A physical resin model was obtained using a solid free-form fabrication method through a layer-by-layer building process. The RP model was embedded, burned, and cast using a titanium alloy (Ti6Al4V, wt%, aluminum 5.5, vanadium 4.5, iron 0.3, silicon 0.15, carbon 0.1, nitrogen 0.05, hydrogen 0.015, and oxygen 0.15; Northwest Research Institute of Nonferrous Metal, Baoji, Shaanxi, China). A titanium grafting plate was thus obtained (Fig. 1). Homogeneously distributed holes of 3-mm diameter on the body of the plate and 2-mm diameter on the footplates were then drilled. Routine post processing, including trimming, sandblasting and polishing, was performed and then sterilized for use. Additionally, a resin stent was designed and constructed for intraoperative navigation. The procedure of manufacture and intraoperative application of the stent was reported in our previous work (Zhou et al., 2011).

Eight weeks after extraction of the teeth, the subjects underwent mandibulectomy with the periosteum preserved, and immediate reconstructive surgery using the titanium grafting plate. The entire thickness of the posterior iliac crest was harvested, with the subject in the prone position. The cortical bone was removed.

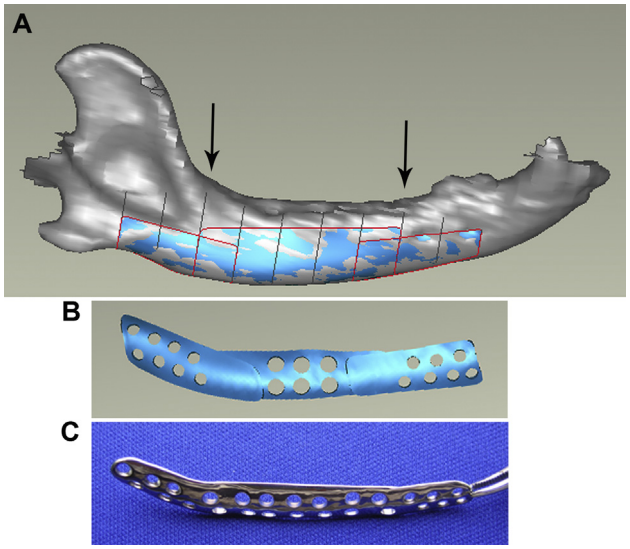

Fig. 1. Computer aided design and fabrication of a custom grafting plate. A, a 40-mm defect was designed in the de-dentated right mandibular body (region between the two arrows). To design the custom grafting plate, the left mandible was mirrored (blue) to substitute the defect area of the right mandible (silver–grey). The buccal surface of the mirrored image was used to form the plate. An extended footplate was designed at both ends based on the host right mandible surface. B, a solid model was created by thickening the surface of the grafting plate and footplate. C, a titanium grafting plate was obtained by rapid prototyping and casting technique.

Cancellous bone was trimmed to fit the grafting plate and fixed onto it with 2–4 stainless wires (diameter, 0.2 mm). The plate-graft complex was then fixed to the residual mandible to bridge the defect (Fig. 2), and the wound was sutured in layers. After the operation, penicillin (0.8 million units) was given intramuscularly twice a day for 5 days. Unrestricted ambulation was permitted. A

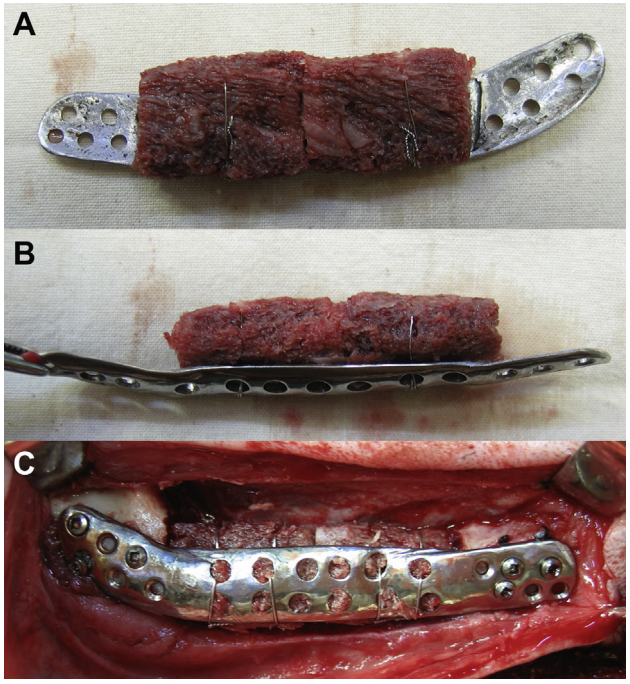

Fig. 2. Surgical procedure: A&B, cancellous iliac blocks were trimmed and fixed onto the grafting plate with stainless wires. C, the plate-graft complex was fixed to the residual mandible to repair the defect.