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ORIGINAL ARTICLE CRANIOFACIAL/MAXILLOFACIAL

Reconstruction of Mandibular Contour Using Individualized High-Density Porous Polyethylene (Medpor®) Implants Under the Guidance of Virtual Surgical Planning and 3D-Printed Surgical Templates

Yu Wang[1] · Yiqun Zhang[1] · Zhen Zhang[1] · Xiang Li[1] · Jianwei Pan[1] · Jihua Li[1]

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Abstract
Background The mandibular contour plays a significant role in the beautiful and youthful look but the reconstruction remains a challenging problem. The objective of this study was to evaluate the use of individualized high-density porous polyethylene (Medpor®) implants for comprehensive reconstruction of mandibular contour with the aid of computer-aided design/computer-aided manufacturing (CAD/CAM).
Methods From 2010 to 2014, 12 patients with mandibular contour deformities were enrolled in our retrospective study. Mandible models and individualized surgical templates were fabricated by three-dimensional (3D) printing and Medpor® implants were made according to the surgical templates. The Medpor® implants were used for both unilateral and bilateral mandibular contour deformities. In four cases, simultaneous mandibular orthognathic surgery was performed with unilateral mandibular contour reconstruction.
Results Eleven patients had a reposeful postoperative recovery with no complication. Delayed infection was shown in one patient and the Medpor® implant was removed. All the 11 patients had the mandibular contour reconstructed satisfactorily.
Conclusion The technique and cases presented demonstrate the utility of Medpor® implants with CAD/CAM in comprehensive mandibular contour reconstruction.

✉ Jihua Li
leejimwa6698@sohu.com

[1] State Key Laboratory of Oral Diseases, National Clinical Research Center for Oral Diseases, Department of Orthognathic and TMJ Surgery, West China Hospital of Stomatology, Sichuan University, Chengdu 610041, China

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Keywords Medpor® · Mandibular contour reconstruction · CAD/CAM

Introduction

Mandibular contour including mandibular angle, inferior border and chin is considered to be an attractive aesthetic factor in the beautiful and youthful look. Mandibular contour deformities can be a result of trauma, malformations, or iatrogenic surgical defects. Treatment options for mandibular contour deformities include autogenous tissue grafts and alloplastic implantation. Autogenous tissues are usually preferred but various alloplasts have been investigated for advantages in graft shaping and less surgical time [1, 2]. Many alloplastic biomaterials have been reported in mandibular plastic surgery, such as silicone, expanded polytetrafluorethylene (GoreTex®), mersilene mesh and high-density porous polyethylene (Medpor®) [3].

Medpor® was developed in the early 1970s and been used widely for facial reconstruction and aesthetic augmentation since the 1990s [4, 5]. It is favored for less resorption and long-term stability. Moreover, it can be easily shaped and fixed. It is slightly flexible at room temperature and becomes malleable in hot water [2]. It is considered to be a long-lasting biomaterial with a low frequency of complications and high overall patient satisfaction [6].

In this study, we designed and made surgical templates by computer-aided design/computer-aided manufacturing (CAD/CAM), rapid prototyping (RP) and three-dimensional (3D) printing. Individualized Medpor® implants were trimmed according to surgical templates to reconstruct the mandibular contour. The technique was used for both unilateral and bilateral mandibular contour deformities. And in four cases, simultaneous mandibular orthognathic surgery was performed with unilateral mandibular contour reconstruction.

Patients and Method

Preoperative Design

From March 2010 to October 2014, twelve patients with mandibular contour deformities underwent mandibular contour reconstruction with Medpor® implants in our hospital. Patient ages ranged from 18 to 43 years (average age 26.1 years). The details of patients are shown in Table 1. All medical practice followed the Declaration of Helsinki on medical protocol. The study was approved by the ethics committee and all participants signed an informed consent agreement.

All patients received spiral CT scans and the data of digital imaging and communication in medicine (DICOM) format was processed with Mimics software version 12.0 (Materialise, Leuven, Belgium). The craniofacial skeleton was visualized with a slice reconstruction interval of 0.5 mm in a 3D display for evaluation of the mandible. Different surgical techniques required different template designs as follows. After that, the data were transported to a CAM machine. The mandible model and individualized surgical templates were fabricated in a laser prototyping system (PTY Medtech Co., Ltd. Shenzhen).

Unilateral Mandibular Contour Reconstruction

For six patients with unilateral mandibular contour deformities, Mimics software version 12.0 and three-matic software version 8.0 (Materialise, Leuven, Belgium) were used. The mandibular contour was reconstructed by mirroring the normal contralateral mandible. Individualized Medpor® implants and accurate implanted location were designed to reconstruct a symmetric mandibular contour (Fig. 1).

Bilateral Mandibular Contour Reconstruction

Three patients presented with bilateral mandibular contour deformities. An ideal mandibular contour was reconstructed according to the criteria in a formal study. The new gonion (Go') should be 2.5 ± 0.5 cm below the auricular lobule; it should be located in the normal range of the mandibular plane (MP) angle (FH–MP = 31.1° ± 5.6°) and should be on the angle bisecting the MP–RP (ramus plane) [7]. Individualized Medpor® implants and accurate implanted location were designed on both sides using the software mentioned above (Fig. 2).

Table 1 Patient details

Patient no.	Age, year/sex	Causes	Type of mandibular contour reconstruction	Follow-up, mo.
1	23/female	Development	U	9
2	26/female	Iatrogenic factor	B	12
3	22/male	Development	U with SO	12
4	18/male	Development	U with SO	32
5	32/female	Iatrogenic factor	B	10
6	43/female	Trauma	U	7
7	25/female	Development	U	9
8	20/male	Development	U with SO	14
9	22/female	Development	U	7
10	29/female	Iatrogenic factor	B	9
11	30/female	Development	U with SO	12
12	23/female	Development	U	10

U: unilateral mandibular contour reconstruction

B: bilateral mandibular contour reconstruction

SO: simultaneous orthognathic surgery

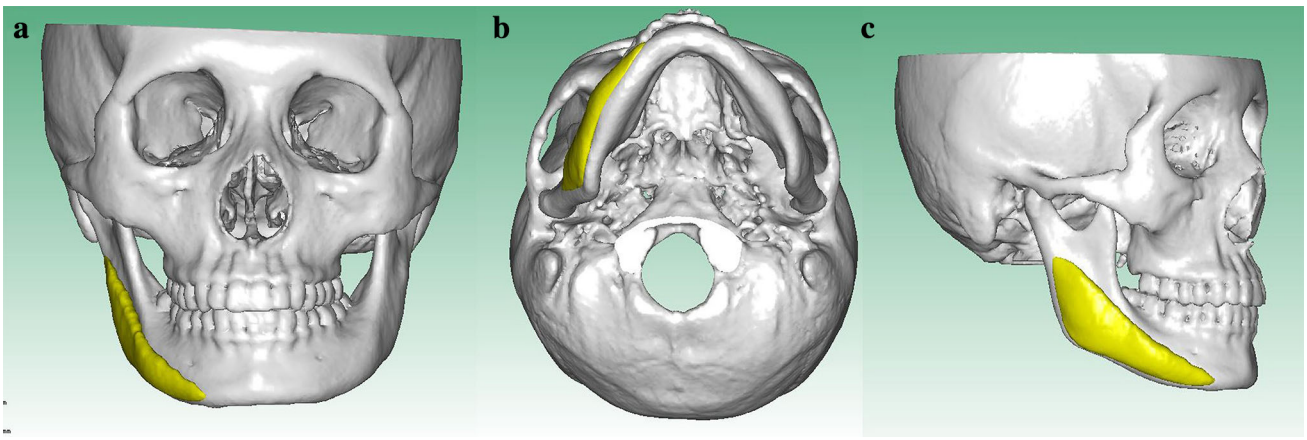

Fig. 1 Designed individualized Medpor® implant and the accurate implanted location of unilateral mandibular contour reconstruction **a** frontal view **b** worm's eye view **c** lateral view

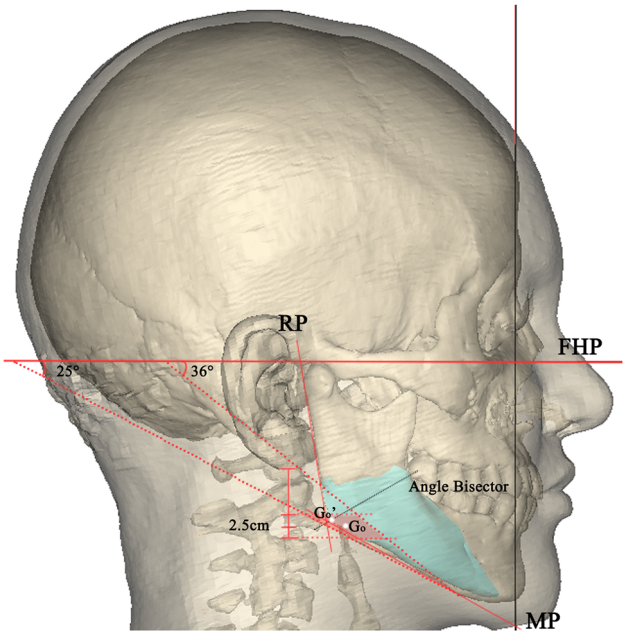

Fig. 2 Designed individualized Medpor® implant and the accurate implanted location of bilateral mandibular contour reconstruction. The new gonion (Go') should be located in the red region and on the angle bisector of the MP–RP simultaneously. The green region indicates the bone to be removed from the mandible. *FHP* frankfurt horizontal plane, *RP* ramus plane, *MP* mandibular plane, *Go* original gonion, *Go'* new gonion

Simultaneous Mandibular Orthognathic Surgery with Unilateral Mandibular Contour Reconstruction

Four patients presented with mandibular contour deformities as well as mandibular retrognathism or protrusion. Simultaneous mandibular orthognathic surgery including sagittal split ramus osteotomy (SSRO) or intraoral vertical ramus osteotomy (IVRO) was used with mandibular contour reconstruction. Due to the limitation of virtual orthognathic surgery planning, only conventional model surgery was used to determine the movement of the mandible. Individualized Medpor® implants and the implanted location were designed preoperatively using the mirroring technique mentioned above.

Surgical Techniques

All procedures were performed under general anesthesia using nasotracheal intubation. The outer cortex of the ramus, the mandibular body region and the inferior margin of the mandible were fully exposed through an intraoral incision. SSRO or IVRO was first performed for patients with malocclusion. Prefabricated Medpor® (Porex Surgical Inc., Newman, GA, USA) implants were first trimmed according to the surgical template. Then we soaked the implants in 90 °C normal saline and bent them to fit the outer cortex of the ramus and the mandibular body. After cooling, internal fixation was achieved using titanium screws. A negative pressure drainage tube was applied for 3 days post operation. Normal anti-infection and support therapy were adopted post operation.

Results

Medpor® implants shaped according to the surgical template were implanted and fixed to the desired position successfully during the operation. All the patients recovered well with primary healing except that one implant (patient 4) was infected and removed after 1 month. No complications such as rejection or nerve injury symptoms occurred. In all the 11 cases, acceptable facial contour was achieved postoperatively. The implants were found to be fixed to the surrounding tissue and the mandibular

reconstruction was reconstructed accurately at 7- to 14-months' follow-up.

Case Reports

Patient 1

A 23-year-old female patient presented with an asymmetric mandibular contour (Fig. 3a, c). Intraoral examination showed no malocclusion or any tooth defect. The individualized surgical template was designed based on spiral CT scan data (Fig. 1). And with the aid of rapid prototyping and 3D printing, both the mandible model and the surgical template were fabricated (Fig. 4).

Unilateral augmentation of the mandible was performed in September 2014 under general anesthesia. The inferior part of the ramus and the mandibular angle region were fully exposed through an intraoral operative approach.

Fig. 3 A 23-year old female patient with asymmetric mandibular contour. **a** Frontal view before operation. **b** Frontal view 9 months post operation. **c** Lateral view before operation. **d** Lateral view 9 months post operation

According to the individualized surgical template, a Medpor® implant was trimmed appropriately and implanted in the designed position outside the right ramus. Titanium screws were used to fix the implant to the accurate location with a transbuccal instrument (Fig. 5).

There were no complications during the 9-month follow-up. The mandibular contour was reconstructed and a satisfactory facial appearance for both patients and surgeons was obtained (Fig. 3b, d).

Patient 2

A 26-year-old female patient who had undergone an unfavorable mandibular angle osteotomy was referred to us for mandibular contour deformities. Physical examination revealed mandibular angle defects on both sides (Fig. 6a, c). Thus, individualized surgical templates were designed on both sides (Fig. 2). The templates were fabricated with the aid of rapid prototyping and 3D printing (Fig. 7). Bilateral augmentation of the mandibular body using Medpor® implants was performed in July 2013 under general anesthesia. There were no complications during the 1-year follow-up. The mandibular contour was reconstructed and a satisfactory facial appearance for both patients and surgeons was obtained (Fig. 6b, d).

Patient 3

A 22-year-old male patient was referred to us with an asymmetric mandibular contour. Physical examination showed an obvious mandibular contour defect on the left side as well as a mild mandibular protrusion (Fig. 8a, c). Thus,simultaneous mandibular orthognathic surgery with left mandibular contour reconstruction was designed to correct the mandibular deformities. The individualized surgical template was fabricated with the aid of rapid prototyping and 3D printing.

After 1 year of orthodontic treatment, bilateral SSRO and augmentation of the left mandible using Medpor® implant was performed in March 2011 under general anesthesia (Fig. 9). There were no complications during the 1-year follow-up. Improvement in both profile and mandibular skeletal contour was achieved after the surgery. The asymmetric mandibular contour was not perfectly reconstructed postoperatively because of the different thickness of soft tissue (Fig. 8b, d).

Discussion

Reconstruction for mandibular contour is an important part in the aesthetics of the lower face. Autogenous grafts continue to be regarded as suitable replacement materials.

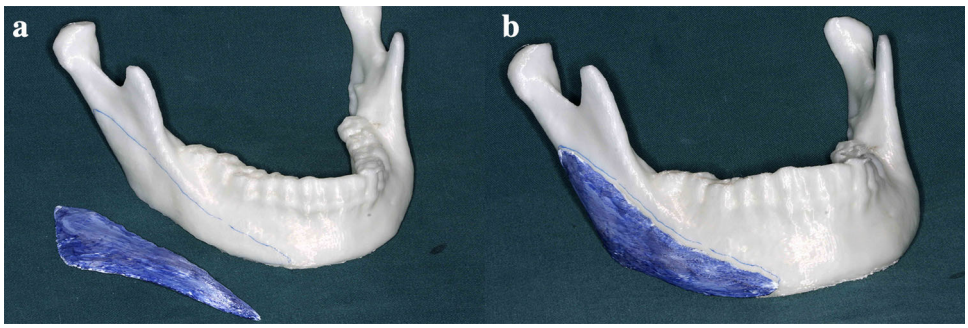

Fig. 4 **a** The mandible model and surgical template fabricated by 3D printing. **b** The surgical template can accurately reconstruct the mandibular contour on the mandible model

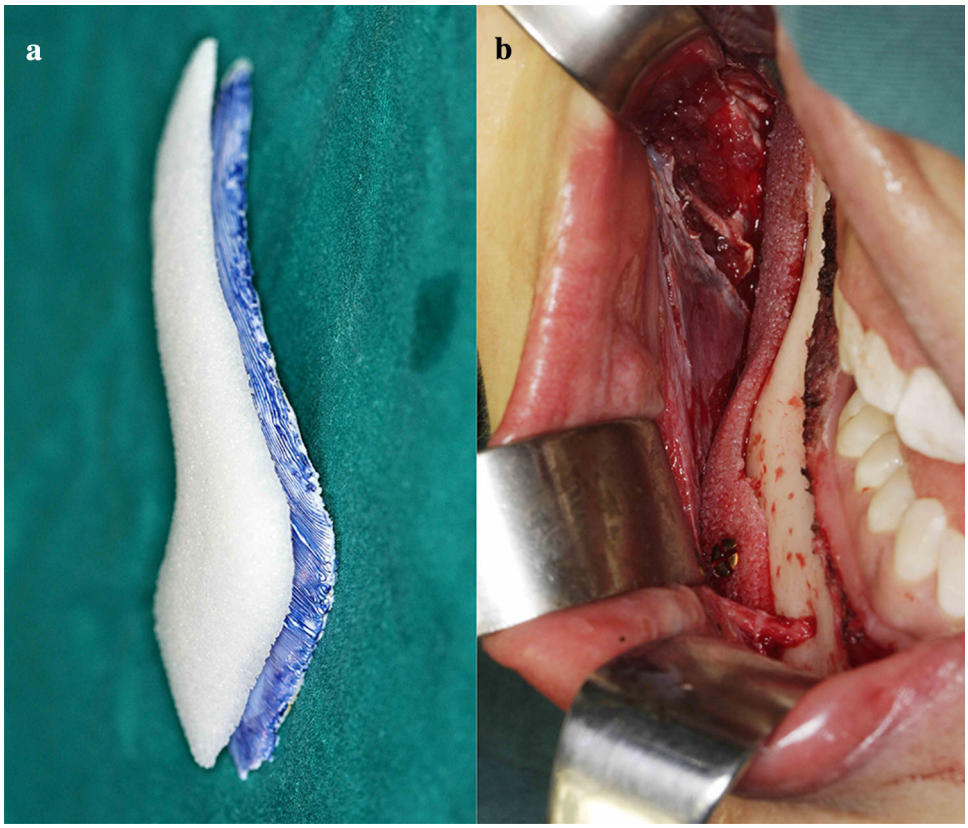

Fig. 5 **a** Medpor® implant was trimmed according to the surgical template during the operation. **b** Medpor® implant was placed outside the atrophy region of mandible and fixed with titanium screws

However, there remain several drawbacks including higher biologic costs, donor-site morbidity, difficulty in modeling the graft and graft resorption. Intraoperative time, hospital admission and recovery time are also major concerns of autogenous bone grafts [8, 9]. These drawbacks resulted in the development of alloplastic implants. Different kinds of alloplastic biomaterials are used as substitutes of autogenous bone to reconstruct the mandibular contour.

Titanium precisely fabricated by RP technology was reported in our former study to correct mandibular ramus defect [10]. However, titanium is not a preferred choice for patients with mandibular contour deformities. The connection between titanium and bone is a mechanical bond rather than the powerful chemical osteointegration. Besides, some patients may complain of sensory disturbance after implantation of a bulky metallic prosthesis. Other biomaterials including silicone, GoreTex®, hydroxyapatite and Medpor® are also used to reconstruct mandibular defects [3]. Silicone and GoreTex® are much softer than Medpor®. Pressure from the overlying soft tissue allows these implants to conform more readily to the patient's original bone [11]. However, silicone does not promote tissue ingrowth and causes capsulation and migration of the implant [2]. Also, the chronic inflammatory process increases the late infection rate [3]. GoreTex® shows less biocompatibility and stability but a relative higher infection rate compared to Medpor® [12].

Medpor® is a widely used alloplastic biomaterial for craniofacial deformities. It is manufactured from a liner high-density polyethylene to create an interconnecting,

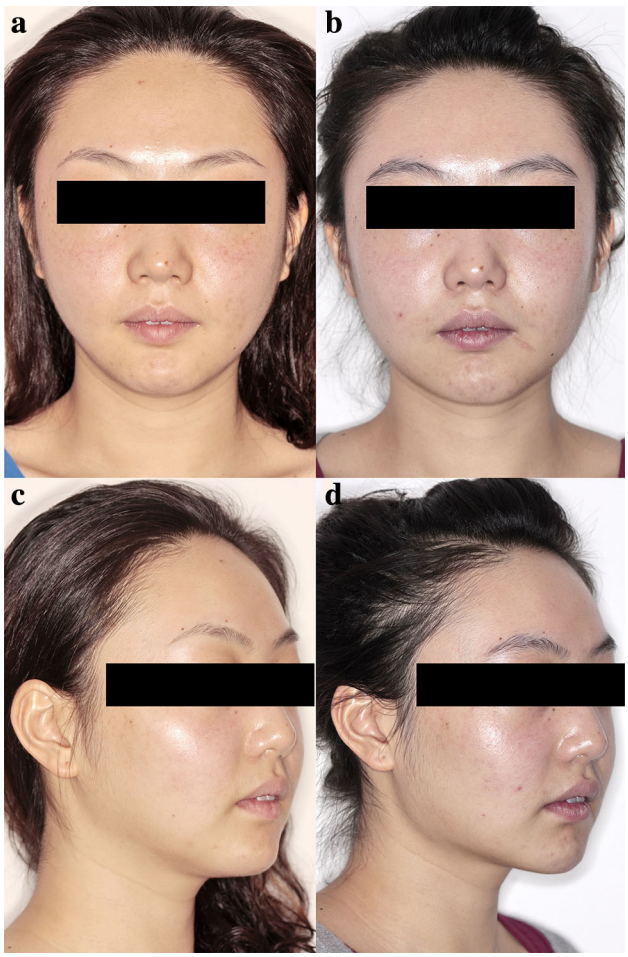

Fig. 6 A 26-year-old female patient with bilateral mandibular angle defect. **a** Frontal view before operation. **b** Frontal view 1 year post operation. **c** Lateral view before operation. **d** Lateral view 1 year post operation

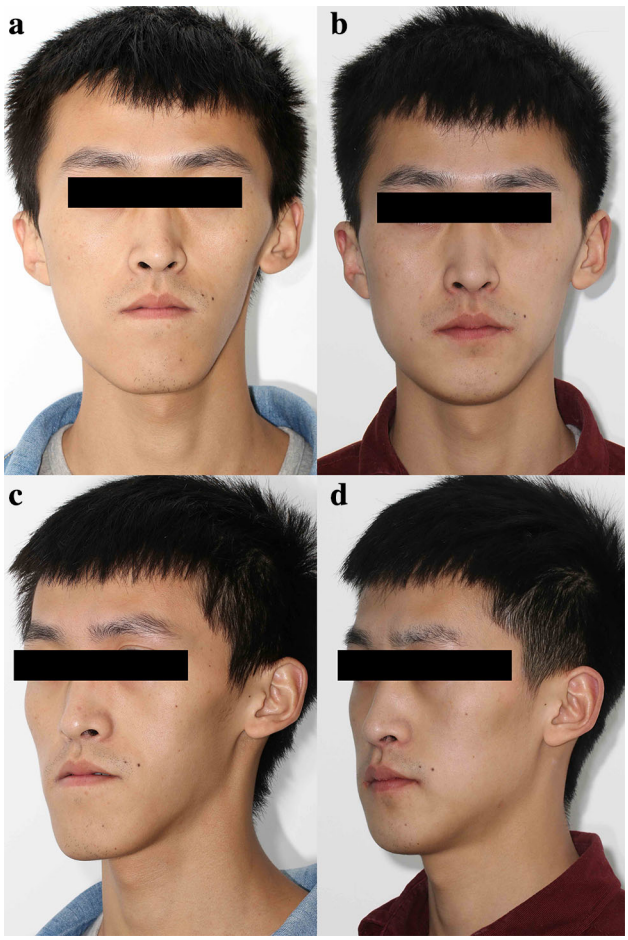

Fig. 8 A 22-year-old male patient with asymmetric mandibular contour. **a** Frontal view before operation. **b** Frontal view 1 year post operation. **c** Lateral view before operation. **d** Lateral view 1 year post operation

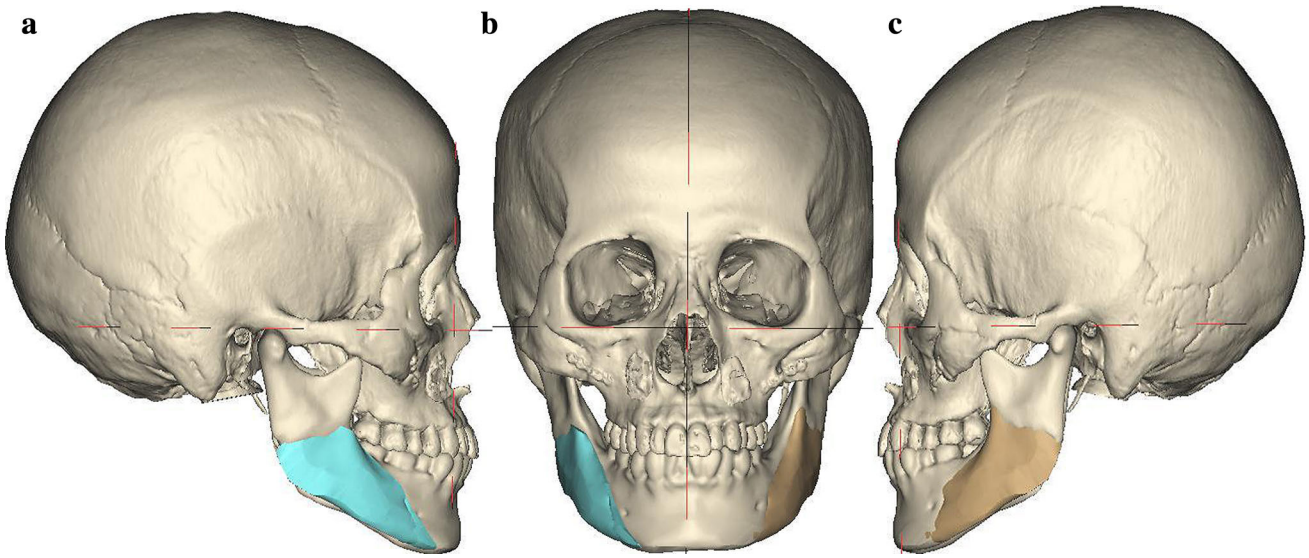

Fig. 7 Designed individualized Medpor® implants and the accurate implanted location of bilateral mandibular contour reconstruction **a** right view **b** frontal view **c** left view

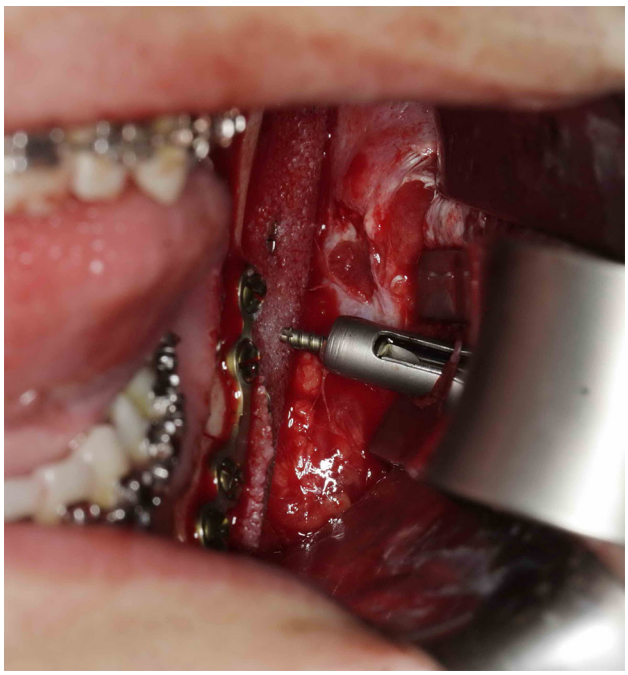

Fig. 9 Sagittal split ramus osteotomy (SSRO) was first performed and the Medpor® implant was placed outside the atrophy region of mandible and fixed with titanium screws

omnidirectional and porous network. It can promote the ingrowth of new bone and connective tissue with related vascularization [13, 14]. Besides, Medpor® is nonabsorbable and nonallergenic with a low infection rate and long-term stability. Thus, it has been considered to be an excellent alternative to autogenous grafts for facial skeletal augmentation [6].

The traditional way to reconstruct lower facial defects using Medpor® is to manually carve the prostheses and then fix them to the defect areas. The final aesthetic result is largely dependent on the surgeons' skills and experience [15]. Accurate implant location and shape of the implant can hardly be ensured. Angela Ridwan–Pramama reported that unsatisfactory appearance scored the highest in postoperative complications (10.1%) among patients treated with Medpor® implantation, and the rate went up to 18.2% among patients with asymmetric mandibular appearance [16]. Thus, computer-assisted individualized Medpor® implants are recommended for providing a more predictable aesthetic outcome. To the best of our knowledge, RP technology has not been directly applied to Medpor®. Trimming Medpor® implants during the operation according to the individualized surgical templates is still the most convenient computer-assisted technique for mandibular contour reconstruction [17].

In our retrospective study, CT data were used to manufacture the mandible model and design the individualized surgical templates for implantation. We used the mirror technique for unilateral mandibular contour reconstruction. Appropriate mandibular contour criteria proposed by a former study were used to manage bilateral cases [7]. Simultaneous mandibular contour reconstruction with orthognathic surgery was designed by model surgery and the methods above. Most patients had an ideal clinical outcome. Delayed infection only occurred in one patient who underwent simultaneous orthognathic surgery with mandibular contour reconstruction and the Medpor® implant was removed. Significant aesthetic improvement was achieved in most cases. The clinical outcomes of simultaneous orthognathic surgery with mandibular contour reconstruction were not as optimal as mandibular contour correction alone. We attributed the less optimal results to the limitation of virtual surgery planning in orthognathic surgery. Also, soft tissue change could not be simulated.

Our clinical experience introduced a computer-assisted method to reconstruct the mandibular contour by individualized surgical templates. With the development of virtual surgery planning, further studies are needed to get more accurate results in simultaneous orthognathic surgery with mandibular contour reconstruction. An optimal effect could not be achieved by implantation of alloplastic materials alone for medium to large sized bone defects. And the mandibular contour deformities can be more complex with soft tissue defects. More consideration should be taken by clinical doctors.

Conclusions

Our study has shown the utility of reconstruction of mandibular contour by Medpor® implantation using CAD/CAM and associated technologies such as rapid prototyping and 3D printing. Virtual surgical planning will serve as a reliable assistance to provide more optimal clinical outcomes.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts of interest to disclose.

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