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ORIGINAL ARTICLE

Introduction of temporomandibular joint and skull base combined reconstruction by autogenous bone graft

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Abstract

Objective This study introduces the application of autogenous bone graft for the reconstruction of temporomandibular joint (TMJ) and skull base combined defects.

Materials and methods Patients treated with autogenous bone grafts for reconstruction of the TMJ and skull base were reviewed. All patients underwent virtual surgical design to confirm the osteotomies of the combined lesion and the selections of autogenous bone graft, fabrication of surgical templates to transfer the plan to actual operation, and reconstruction of autogenous bone graft for the TMJ and/or skull base. Surgical outcomes were assessed by clinical examinations and radiological data.

Results Twenty-two patients were involved in this study. Ten patients underwent reconstruction of the skull base by a free iliac or temporal bone graft and preservation of the TMJ. Twelve patients underwent skull base reconstruction by the same methods and total reconstruction of the TMJ by half sternoclavicular joint flap or costochondral bone graft. No severe complications occurred after surgery. The occlusion relationship was stable and similar to that of the preoperative state. The pain and maximal interincisal opening were significantly improved by the 101.2-month follow-up.

Conclusion Autogenous bone graft is a good alternative for repairing the TMJ and the skull base structure and function.

Clinical relevance The study introduced the application of autogenous bone graft for the reconstruction of temporomandibular joint and skull base combined defect, which is a good way to repair the defect and restore the function.

Keywords Temporomandibular joint · Skull base · Autogenous bone graft · Reconstruction · Liang Huo and Zixiang Han are co-first authors for this study.

Introduction

The temporomandibular joint (TMJ) is composed of the glenoid fossa, condylar head, and disc. The glenoid fossa is part of the skull base. Therefore, TMJ and skull base combined defects are usually caused by tumors or tumor-like lesions, such as synovial chondromatosis, giant cell lesions, osteochondroma, and synovial chondrosarcoma [1–6]. To prevent further bony erosion and destruction of the crucial anatomical structures, the combined lesion must be resected completely. Moreover, the joint and skull base need to be reconstructed for the recovery of normal bone structure and maxillofacial function.

Previously, the reconstruction of these types of combined defects was a major challenge for neurosurgeons, ENT surgeons, and maxillofacial surgeons. Most studies advocated only the removal of the lesions and any involved

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adjacent structures with no reconstruction or just soft tissue graft filling. Since the 2010s, two reconstruction methods, autologous bone graft and artificial prostheses, have been introduced to repair large defects [3, 5–7]. Although the artificial prosthesis is an innovative and effective method for TMJ-skull base combined reconstruction [8], the use of autologous bone graft provides patients with an alternative option when patients have contraindications or unwillingness to artificial prosthesis.

Shared experiences of autogenous bone graft were presented in our previous case report study [9]. The free iliac bone graft was used for skull base reconstruction, and half of the pedicled sternoclavicular joint was used for repair of the condyle with the assistance of digital medicine. Based on our previous report of autologous bone graft reconstruction, our teams classified the TMJ and skull base combined defects and explored additional methods of reconstruction with autogenous bone graft. The free temporal bone and costochondral bone were grafted to the skull base and joint, respectively [10–12]. Digital medicine was also used for the harvest and fixation of autogenous bone graft.

In this study, 22 cases in which patients were diagnosed with TMJ and skull base combined lesions, treated with autogenous bone graft, and who had a mean follow up of 101.2 months were reviewed. All procedures, including indications, preoperative virtual surgery design, and surgical techniques and follow-ups, were introduced in detail to increase surgeon awareness regarding methods of TMJ and skull base reconstruction.

Methods

Patients

This was a retrospective study conducted at the Department of Oral Surgery, Shanghai Ninth People's Hospital between March 2006 and June 2018. Cases in which patients were treated with autogenous bone graft for TMJ and skull base combined lesions reconstruction were reviewed. This study was approved by Shanghai Ninth People's Hospital Human Research Ethics Committee. Moreover, the principles outlined in the Declaration of Helsinki were followed. All patients were informed about the surgical purpose, surgical protocol, recovery period, and possible complications, and informed written consent was obtained from all participants.

Preoperative virtual analysis and design

Preprocessing of enhanced CT data

All patients underwent an enhanced CT scan of the entire skull, mandible, maxilla, TMJ, and upper neck with 0.625 mm slice thickness. CT data with DICOM format were processed using Mimics software 18.0 (Materialize Co, Leuven, Belgium) to calculate the 3D models of the whole skull, mandible, major blood vessels and nerves, and lesions (Fig. 1).

Resection and reconstruction predesign

According to the MRI and CT data, there were two types of resection and reconstruction methods, which are classified into types A and B. Type A lesions involved the fossa and skull base, while the condyle and the disc were normal. Type B lesions included the fossa, skull base, and condyle, while the disc was not checked in MRI images.

For type A, resection and reconstruction of the TMJ-skull base combined lesions was simulated in Mimics software, as explained in the following steps:

① The zygomatic arch, condyle, and temporal bone window were temporarily osteotomized for anterior, inferior, and superior exposures of the lesion (Fig. 2A).

② The lesion was virtually resected in its entirety using two osteotomy planes anterior and posterior to the skull base. When designing the resection, the related vital structures, including the internal carotid artery, jugular vein, and auditory ossicle, were carefully preserved (Fig. 2B).

③ For the skull base reconstruction, the temporal bone graft was rotated to the position of the skull base to repair the perforation, while the temporal bone region was covered by the Ti mesh or Medpore (Fig. 2C). When the bone defect of skull base was huge and the temporal

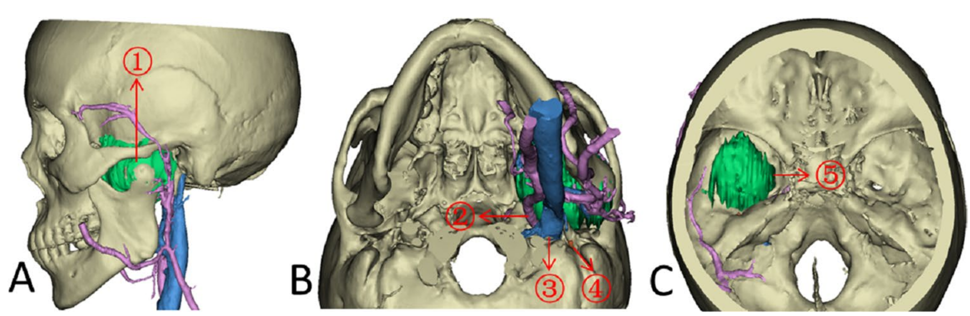

Fig. 1 The virtual analysis of 3D models included the whole skull, mandible, major blood vessels and nerves, and lesions. **A** Lateral view. **B** Inferior view. **C** Superior view. ①: The lesion. ②: Internal carotid. ③: Internal jugular. ④: Facial nerve. ⑤: Skull base perforation

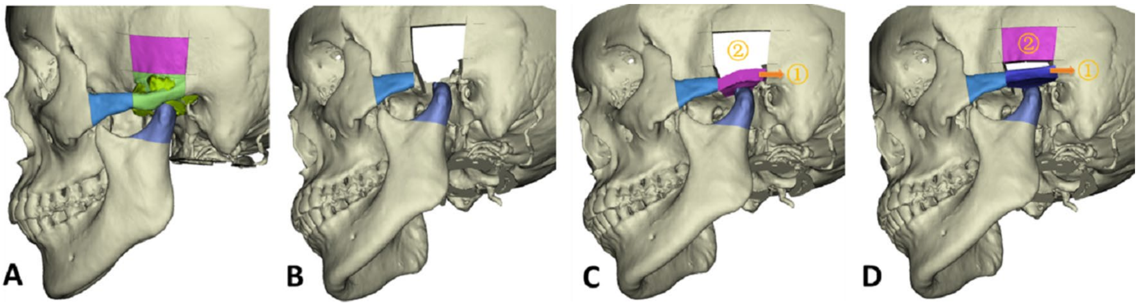

Fig. 2 Type A: resection and reconstruction of the skull base and fossa with preservation of the condyle. **A** The design of the simulated resection region. **B** The defect after simulated resection. **C** First method for reconstruction, using rotation of the temporal bone graft and Ti mesh or Medpore (① indicates the temporal bone graft, ② indicates the fixation of Ti mesh or Medpore). **D** Second method for reconstruction using the free iliac bone graft (① indicates the iliac bone graft, ② indicates the repositioning of the temporal bone)

bone could not cover, the free iliac bone was selected and grafted to the skull base (Fig. 2D).

For type B, the simulation of surgery was designed as follows:

① The zygomatic arch and temporal bone window were temporarily osteotomized, allowing anterior and superior exposures of the lesion, and the condyle or ramus was dissected at the inferior border of the lesion (Fig. 3A).

② The anterior and posterior osteotomy planes of the skull base were designed for removal of the entire lesion. The related vital structures were also carefully preserved as mentioned above (Fig. 3B).

③ The reconstruction of the skull base was performed as previously described with type A methods. For reconstruction of the condyle, the half-pedicle sternoclavicular joint flap was harvested and fixed on the posterior edge of the ramus for more than 40 years old patient (Fig. 3C). For less than 40 years old patient, the free costal subchondral bone was selected and grafted and fixed on the surface of the ramus (Fig. 3D).

Surgical procedure

All patients received general anesthesia with nasal intubation. The surgical procedure was introduced in detail in a previous study and described by the following steps [9, 11, 12].

① Incision: A modified preauricular incision with a temporal extension was used for type A (Fig. 4A). Type B combined a postmandibular or a submandibular approach (Fig. 5A).

② Dissection of the facial nerve: For type A, the trunk of the facial nerve was identified and preserved. The facial nerve was retracted to expose the lesion. For type B, if the lesion was too large to be clearly exposed or the intraoperative frozen pathology was malignant, then the facial nerve was considered to cut sufficiently for the exposure and resection intactly of the lesion (Figs. 4B and 5B). The facial nerve was sutured after lesion removal.

③ Resection of the lesion: The zygomatic arch and condyle were osteotomized, and temporal craniotomy was performed with the assistance of a surgical template that was fabricated preoperatively. Then, anterior and posterior osteotomies of the skull base were performed by guided surgical

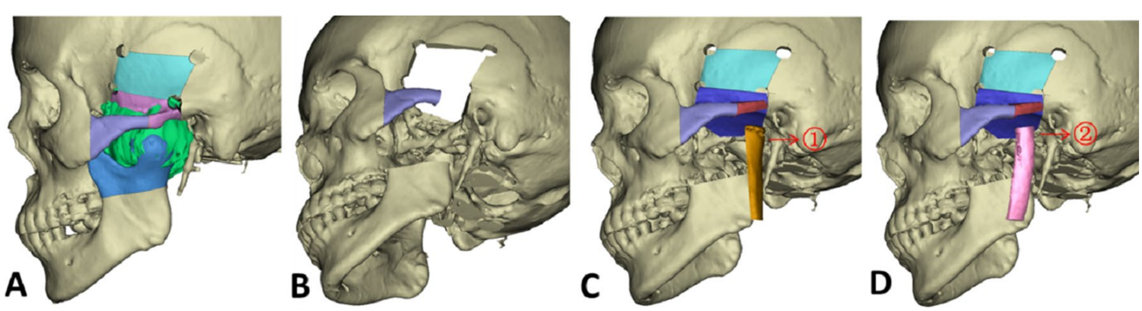

Fig. 3 Type B: resection and reconstruction of the skull base, fossa, and condyle. **A** The design of the simulated resection region. **B** The defect after simulated resection. **C** First method for reconstruction using a graft of the half-pedicle sternoclavicular joint (① indicates the half-pedicle sternoclavicular joint). **D** Second method for reconstruction using a graft of free costal subchondral bone (② indicates the free costal subchondral bone)

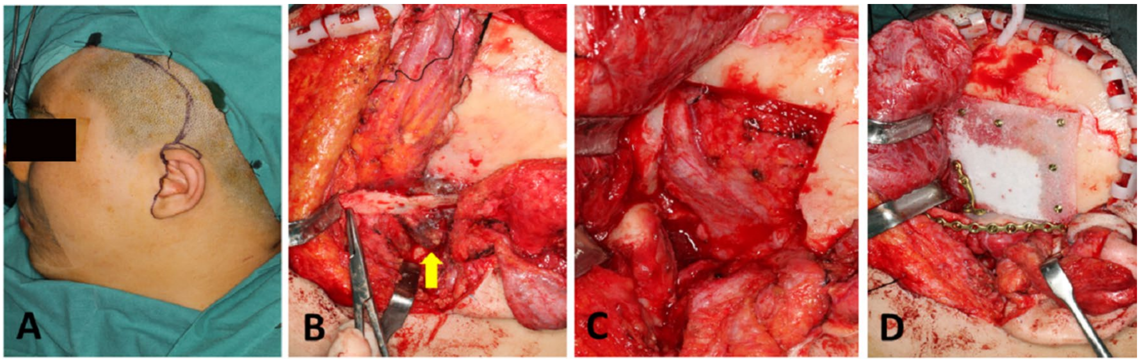

Fig. 4 The surgical procedure for type A. **A** The incision. **B** Exposure of the lesion. **C** The defect after resection. **D** The reconstruction for type A using a temporal bone graft and Medpore

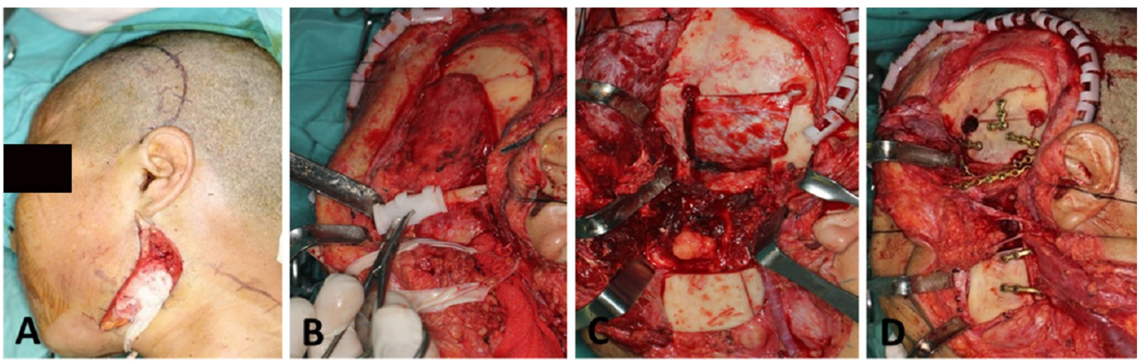

Fig. 5 The surgical procedure for type B. **A** The incision. **B** Exposure of the lesion. **C** The defect after resection. **D** The reconstruction for type B using an iliac bone graft and half pedicle sternoclavicular joint

templates. The lesion was removed completely (Figs. 4C and 5C).

④ Reconstruction of the skull base: A temporal bone graft or iliac bone graft was reshaped or grafted with the help of templates, positioned and fixed to repair the skull base and zygomatic arch. If the temporal bone graft was used for reconstruction of the skull base, the temporal defect was covered by Ti mesh or Medpore (Fig. 4D).

⑤ Intermediate substance: The temporal muscle flap (TMF) was grafted and rotated to cover the fossa surface of the autogenous bone graft.

⑥ Reconstruction of the condyle: For type A, the condyle was repositioned and fixed back. For type B, the half pedicle sternoclavicular joint or free costal subchondral bone was grafted and fixed to the mandibular ramus under stable occlusion (Fig. 5D).

⑦ Free fat filling: Pieces of fat harvested from the previous incisions were wrapped around the condylar head to obliterate any dead space and to prevent infection and the formation of heterotopic bone.

⑧ Finally, the wound was closed in layers with two 18-gauge drains.

Outcome evaluations for the resection and reconstruction

The outcomes of the resection and reconstruction were reviewed by the chart, photos, and follow-up records. Intraoperative indices, including (a) occlusion relationship, (b) endocranium crack, (c) operative time, and (d) bleeding volume, were rechecked. Postoperative craniomaxillofacial general check-ups, including (a) infection, (b) cerebrospinal fluid (CSF) leakage, (c) wound healing, and (d) facial nerve damage, were reviewed from the charts. The displacement or loosening of the autogenous bone grafts was rechecked in CT images at the last follow-up. The pain score obtained using a 10-length visual analog scale and the measurements of maximal interincisal opening (MIO) were compared with preoperative data.

Statistical analysis

Data were analyzed using SPSS software, version 17.0 (SPSS, Chicago, IL). The assessment indices of pain and MIO before and after surgery were compared using repeated measures one-way analysis of variance. A P value of less than 0.05 was considered statistically significant ($P \leq 0.05$).

Results

General information

Twenty-two consecutive patients (22 joints) were reviewed. There were 10 females and 12 males. The mean patient age was 43.2 years (range, 23 to 66 years). Eleven patients were diagnosed with giant cell lesions, 3 patients had synovial chondromatosis combined with giant cell lesions, 3 patients had synovial chondromatosis, 1 patient had condyle chondrosarcoma, 1 patient had TMJ synovial chondrosarcoma, 1 patient had myofibroblastoma, 1 patient had Langerhans cell histiocytosis, and 1 patient had pigmented villonodular synovitis based on the final histopathology. The mean follow-up period was 101.2 months (range, 39 to 186 months) (Table 1).

Intra- and postoperative observations and evaluations

Intraoperatively, 14 patients were type A, and 8 were type B. For type A, 6 cases were treated by free iliac bone graft, and 8 cases were treated by temporal bone graft. For type B, 2 cases were treated with a free iliac bone graft, and 6 cases were treated with a temporal bone graft for reconstruction of the skull base and fossa. Meanwhile, 3 cases were treated with a half-pedicle sternoclavicular joint flap, and 5 cases were treated with costochondral bone graft for condylar repair.

Three patients had an endocranium crack repaired by a Teflon felt (CHEST, Shanghai, China) to prevent cerebrospinal fluid leakage. Four patients underwent temporary cutting and suturing the facial nerve before closing. All patients obtained stable occlusion after the fixation of autogenous bone graft. The mean operative time was 5 h and 15 min (range, 4 h and 35 min to 7 h and 13 min). The average intraoperative surgical bleeding volume was 850 ml (range, 500 to 1400 ml).

Postoperatively, there were no severe complications, such as CSF leakage, secondary meningitis, or wound infection, in any patient. Facial nerve function was recovered at 6 to 12 months after surgery for 18 patients who did not undergo temporary cutting and suturing of the facial nerve. Four patients who underwent treatment of the facial nerve had an improvement in the function of the facial nerve but still showed permanent damage.

From the postoperative CT images (Fig. 6), there was no displacement or loosening of the autogenous bone graft, and the position of the grafted bone was similar to the predesigned plan. Based on the follow-up records, there was a significant reduction from 6.8 ± 1.9 to 1.7 ± 0.4 in pain levels and an improvement from 19.0 ± 9.6 to 28.6 ± 3.4 mm in MIO ($P < 0.05$) (Table 2).

Table 1 Patients' basic information and demographics

Items	Sub-items	Data
Sex	22	
	Female	10
	Male	12
Age (year)	43.2 (range: 23 to 66)	
Diagnosis	22	
	GCL	11
	SC	3
	SC+GCL	3
	Chondrosarcoma	1
	Synovial chondrosarcoma	1
	Myofibroblastoma	1
	Langerhans cell histiocytosis	1
	PVNS	1
Follow-up (months)	101.2 (range: 39 to 186)	

SC synovial chondromatosis, *GCL* giant cell lesions, *PVNS* pigmented villonodular synovitis

Discussion

Primary tumors of the TMJ or skull base may result in bone destruction around this area. Large defects following a total resection of TMJ-skull base combined lesions present challenges to surgical reconstruction. This type of TMJ-skull base combined lesion, which was treated with the use of autogenous bone graft to reconstruct the skull base, fossa, and/or condyle, was reviewed in patients presenting to the Department of Oral Surgery, Shanghai Ninth People's Hospital from 2008 to 2018. The whole procedure of autogenous bone graft reconstruction included the preoperative virtual analysis, surgical stimulation design, intraoperative resection and reconstruction assisted with digital templates, postoperative follow-up, and clinical and radiological examinations.

First, the type of TMJ-skull base combined lesion (including benign and malignant) was confirmed and the lesion range (including the skull base, fossa, condyle, auditory meatus, and infratemporal fossa) was determined using enhanced CT and TMJ MRI. For type A, the contour of the condyle was intact, and the lesion extended to the upper joint compartment. The disc was usually normal and acted as a barrier preventing the lesion from progressing downward. For type B, the lesion penetrated the disc and condyle, or the original condylar lesion moved upward and destroyed

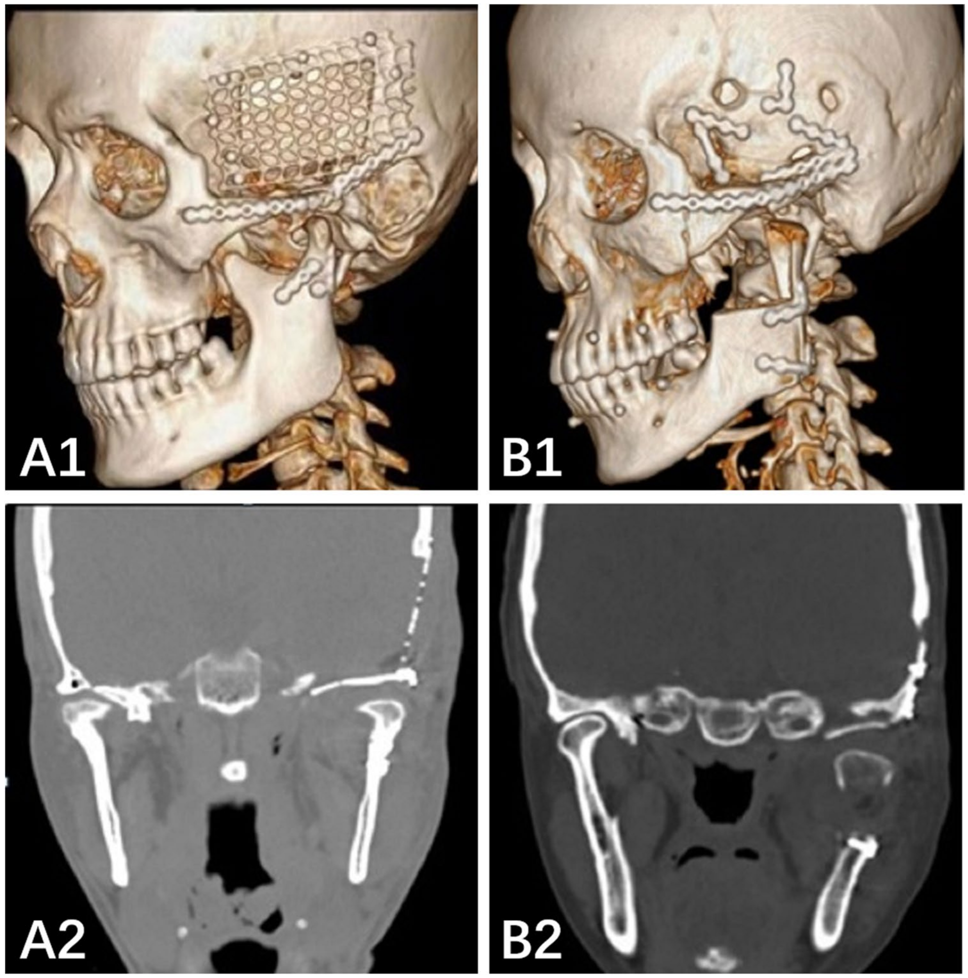

Fig. 6 The reconstruction outcomes. **A1** and **A2**: postoperative CT scan for type A. **B1** and **B2**: postoperative CT scan for type B

the disc, fossa, and skull base. This type of combined lesion should be completely resected. Compared to our previously published classification scheme [9], the combined lesions in the present study were classified into type A or type B lesions. Types A and B lesion classification was based on preservation or lack of preservation of the condyle, which helped determine the difficulty of the surgical plan.

Second, it is important to use digital medicine for preoperative virtual analysis and surgical simulation. Using a 3D reconstruction of the entire skull, mandible, major blood vessels and nerves, and lesion, surgeons are able to determine the lesion's range and its relationship with adjacent anatomic structures, major vessels, and nerves prior to surgery. By mapping the lesion in this way, surgeries are safer and easier [14]. Importantly, virtual resection and reconstruction simulation allow surgeons to confirm the best surgical approach, the location of any high-risk regions, and the best reconstructive approach [16]. In this study, the position and direction of the posterior osteotomy plane required more attention due to its close proximity to the auditory meatus, internal carotid and jugular veins, oval foramen, and eustachian tube. Therefore, the osteotomy plane had to be parallel to the anterior edge of the petrous pyramid. For virtual reconstruction, the shape and size of the autogenous bone graft was predicted, and the position and fixation were previewed. Thus, digital medicine has aided in improving the predictability and control of surgical procedures.

Next, the resection and reconstruction of the combined lesion were performed with the assistance of digital templates that allowed the accurate transfer of predesigned plans to actual surgical procedures. For the skull base, two surgical repair approaches, including free iliac bone graft grafting and temporal bone graft rotation combined with titanium mesh or Medpore, were presented. The temporal bone is the first choice, because of no need secondary donor site. Only for huge skull base defect and the bone insufficient of temporal bone, the free iliac bone would be selected. For the joint, two reconstruction strategies, the use of a half-pedicle sternoclavicular joint for patients > 40 years old or for patients who required chemoradiotherapy after surgery and the use of costochondral bone for patients < 40 years old, were proposed. In this study, the skull base and fossa were repaired, and the condyle was preserved in 14 cases (type A). The skull base, fossa, and condyle

Table 2 The data of intraoperative records, postoperative clinical examinations

Items	Sub-items		Data	P value
Treatment type			22	
	Type A		14	
	Type B		8	
Autogenous bone			22 (skull base), 8 (condyle)	
	Type A	Iliac bone	6	
		Temporal bone	8	
	Type B	Iliac bone	2	
		Temporal bone	6	
		SCJ	3	
		CCG	5	
Facial nerve cutting and suturing temporally			4	
Operative time		5 h and 15 min (range, 4 h and 35 min to 7 h and 13 min)		
Bleeding volume		850 ml (range, 500 to 1400 ml)		
Pain level (VAS)				
	Pre		6.8 ± 1.9	$P < 0.05$
	Post		1.7 ± 0.4	
MIO (mm)				
	Pre		19.0 ± 9.6	$P < 0.05$
	Post		28.6 ± 3.4	

MIO maximal interincisal opening, *SCJ* sternoclavicular joint, *CCG* costal subchondral graft

were reconstructed in 8 cases (type B) using the methods mentioned above. According to follow-up results, none of the patients experienced severe complications, and the patients' mouth opening and pain were significantly improved following surgery. Compared with approaches using combined prosthesis, use of an autogenous bone graft may be more complicated, invasive, and time-consuming. In addition, there are additional risks due to the necessity of a second operation at the donor site. However, surgeries using autogenous bone graft for reconstruction are still a good choice for cases with contraindications to prostheses use, such as allergies and malignant tumors with or without postoperative radiotherapy. Compared with existing reports, autogenous bone grafts are also a good option for TMJ and skull base combined defect [13, 15, 16].

Although several advantages of digital resection and reconstruction of autogenous bone graft were addressed by the current study, some limitations of this study should be declared. First, long-term follow-up should be conducted to determine how the bone graft remolds, paying special attention to the remolding of the free iliac vs temporal bone at the skull base. In follow-up studies, the predesigned and the last postoperative CT data should be merged to indicate and measure remolding. Second, the methodological details of the design, fabrication, and intraoperative use of digital templates were limited; future reports should introduce these procedures in detail.

Conclusion

In conclusion, there is no doubt that autogenous bone graft, as well as a combined or extended prosthesis, is an effective and safe way to reconstruct major TMJ-skull base combined bone defects after radical resection. It should be considered an alternative for TMJ-skull base combined repair.

Availability of data and materials Not applicable

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Zixian Jiao, Xiang Wei, Qingyu Xu, and Abdelrehem Ahmed. The first draft of the manuscript was written by Liang Huo and Zixiang Han and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Ethical approval Not applicable

Research involving human participants and/or animals This research involved no human participants and/or animals, thus including no informed consent or a statement on welfare of animals.

Competing interests The authors declare no competing interests.

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