Mandibular reconstruction using ProPlan CMF: a review

Mandibular Reconstruction Using ProPlan CMF: A Review

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Abstract

ProPlan CMF (Depuy Synthes, Solothurn, Switzerland, and Materialise, Leuven, Belgium) is a computer-aided surgical virtual planning service using an online meeting with professional medical engineers and transfers patient-specific surgical guide to the virtual plan. Moreover, prebent reconstruction plates or patient-specific computer-aided manufacturing-fabricated reconstruction can also be used. This service started in 2011. Currently, it is widely used in Europe. Current status of mandibular reconstruction with ProPlan CMF vertical planning service with the surgical guide was reviewed. The accuracy was excellent in terms of contact of the osteotomized parts and the contact to the remaining skeleton. The authors found that currently, a small number of reports regarding the mandibular reconstruction with virtual planning service and surgical guides are available. These reports also have a small number of cases and short-term follow-up results. In this situation, this review revealed that (1) mainly the resection guides, cutting guides, and patient-specific mandible reconstruction plates were adequately well fitted to the surgical site intraoperatively, (2) the ischemic time might be more reduced than that of the conventional surgery (3) the accuracy of computer-assisted surgery in the mandibular reconstruction was clinically acceptable, and (4) condyle positions after the computer-assisted surgery was mainly normal. The higher additional cost than that of the conventional technique is presently an issue. Large-scale clinical studies and long-term follow-up studies are demanded.

Keywords
- ► mandibular reconstruction
- ► computer-assisted surgery
- ► ProPlan CMF
- ► virtual planning service
- ► surgical guides
- ► patient-specific mandible reconstruction plate
- ► CAD/CAM

ProPlan CMF (Depuy Synthes, Solothurn, Switzerland, and Materialise, Leuven, Belgium) is a computer-aided surgical virtual planning service with professional medical engineers, and transfers patient-specific surgical guides to the virtual plan.[1] There is no necessity to buy expensive software and handle the software which might be difficult to use. Moreover, a prebent reconstruction plate or a patient-specific computer-aided manufacturing (CAD/CAM)-fabricated reconstruction plate also can be used. This virtual planning and surgical guiding service started in 2011. Currently, it is widely used in Europe and North America, but not in Asian countries except Australia. In this review, the current status of mandibular reconstruction with ProPlan CMF vertical planning service and the surgical guide was reviewed.

Case Report

A 67-year-old female patient suffered from a right mandibular pathologic fracture with infected osteoradionecrosis (ORN). The patient had received a radiation therapy of 60 Gy for treating her mandibular squamous cell carcinoma before ORN. The authors planned to perform the segmental resection of the right mandible and immediate reconstruction with the free vascularized iliac bone with the assistance of ProPlan CMF. At first, the computed tomography (CT) of facial and iliac bones was performed (►**Fig. 1**). The digital imaging and communication in medicine data of CT were transferred to ProPlan CMF medical engineers. Second, a web meeting through personal computers and telephone was held by a surgeon

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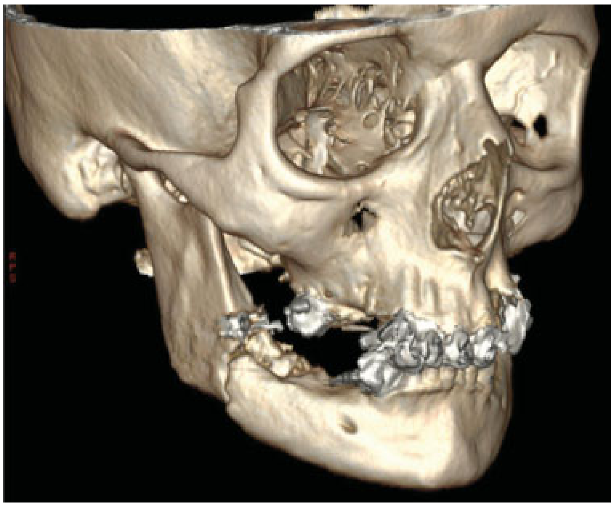

Fig. 1 Preoperative computed tomography of the right mandibular pathological fracture with infected osteoradionecrosis in a 67-year-old female patient.

and a medical engineer. On the web meeting, the resection area of the mandible was decided by the surgeon and colored on the personal computers by a medical engineer (►**Fig. 2A**). The resection area of the mandible was merged on the iliac bone (►**Fig. 2B**), and harvesting part was decided considering the pedicle part, and then, the lateral-medial position of the transplant was determined fitting into the contour of the mandible (►**Fig. 2C**). Finally, the resection guide for mandible and the cutting guide for harvesting the iliac bone were designed (►**Fig. 2D**). The planning and sterilized resection guide for the mandible and cutting guide were sent to the hospital before surgery. Also a stereolithographic model with the transplant as a model on which the parts that should be grinded off to fit the contour were in another color. Surgery was performed under general anesthesia. The right mandible was exposed, and the resection guide was fitted on the mandible with two screws. The resection guide was well fitting (►**Fig. 3A**). The segmental resection of the right mandible was performed. Secondly, the deep circumflex iliac artery (DCIA) was exposed, then, the iliac bone was exposed, and the cutting guide was fitted on the iliac bone with two screws (►**Fig. 3B**). A free vascularized iliac crest bone graft was harvested (►**Fig. 3C**). The DCIA and vein were anastomosed. The harvested free vascularized iliac crest bone graft was inserted to the right mandibular defect and fixation was performed by two miniplates at each end (►**Fig. 3D**). The postoperative CT indicated that the iliac crest bone graft was well fitting (►**Fig. 4**). The patient's face was symmetrical after surgery.

Literature Review

English language medical reports published up to 2015 and indexed in PubMed and Google Scholar were searched with

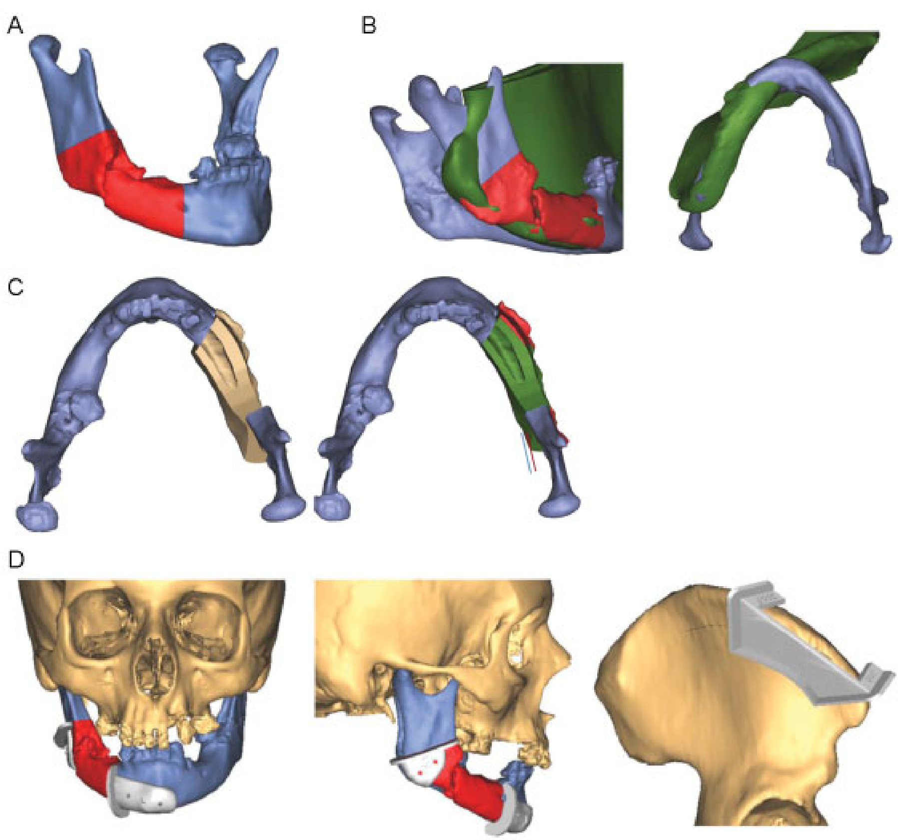

Fig. 2 Obtained images during an online meeting with a medical engineer. (**A**) Creation of the resection part of the mandible (red). (**B**) Choosing a proper section of the iliac bone (green). (**C**) Definition of the parts that have to be reduced and of the necessary length of the vascular pedicle. (**D**) Design of the resection guide and cutting guide.

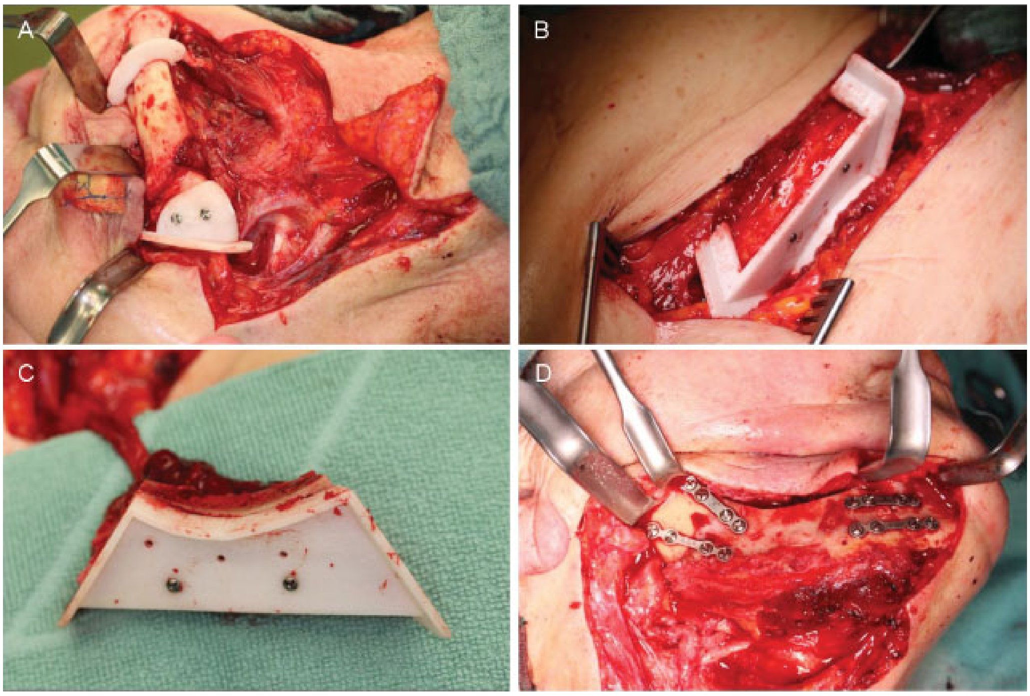

Fig. 3 Intraoperative photographs with the surgical guides. (**A**) Intraoperative fitting of the resection guide. (**B**) Intraoperative fitting of the cutting guide in the ilium. (**C**) Harvested free vascularized iliac crest bone graft with the cutting guide. (**D**) Transplantation of free vascularized iliac crest bone graft.

the keywords; "mandible," "reconstruction," and "proplan." Inclusion criteria were a mandibular reconstruction with ProPlan CMF surgical planning service and the surgical guides. Exclusion criteria were (1) case reports, (2) technical notes, (3) other craniomaxillofacial reconstruction except mandible, (4) reconstruction in dent facial deformity, (5) focusing on a dental implant, (6) using only ProPlan CMF software without the virtual planning service and surgical guides. After literature search, the following points were reviewed: (1) the duration of online meeting, (2) the intraoperative fittings of the cutting and resection guides, (3) the intraoperative fitting of patient-specific mandible reconstruction plate, (4) the comparison of the operative time with those of conventional surgeries without computer-assist, (5) the accuracy of virtual plan, (6) postoperative condyle position, (7) the duration of intensive care unit and postoperative hospitalization, and (8) the additional cost of virtual planning service and surgical guides.

Results

PubMed and Google Scholar found 6 and 63 articles, respectively, and total 69 reports were collected. Seven reports were eliminated due to duplication. All PubMed searched articles were covered by Google Scholar search. Eight articles were excluded because they were written in other languages

Fig. 4 Postoperative computed tomography.

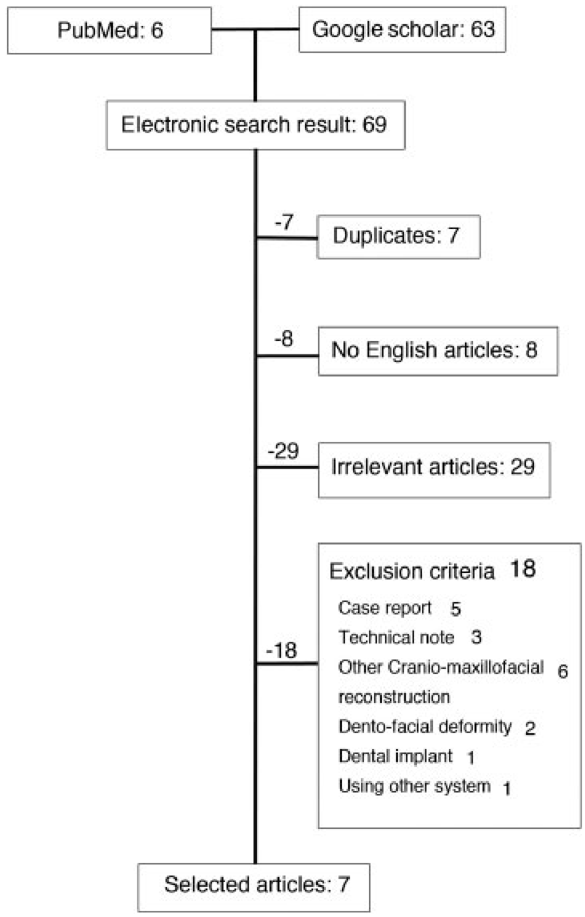

Fig. 5 Flowchart of the systematic review process.

(five in Chinese, one in German, one in Dutch, and one in Spanish). A total of 29 articles were excluded because they were not relevant to the subject. The exclusion criteria excluded 18 articles. Only seven articles were selected in this review (►**Fig. 5**) including one randomized prospective clinical study, and they were published in 2014 or 2015. Each article had small numbers of cases between 4 and 32 cases. Follow-up terms were short from approximately 6 to 12 months, and no clear follow-up term was written in some articles. Type of mandibular reconstruction was mainly primary reconstruction (►**Table 1**).

Time of Online Meeting

Wilde et al report that the mean of the duration of online meeting with medical engineers for surgical planning is 35 minutes (range: 20–75 minutes) in mandibular reconstruction with the surgical guide and patient-specific mandible reconstruction plates.[2]

Intraoperative Fitting of Cutting Guide and Resection Guide

This review could find no scientific value in the intraoperative fitting of the surgical guide. Wilde et al report the surgeon's opinion regarding the intraoperative fitting of the surgical guide. The intraoperative fitting of the cutting guide ($n = 30$) and resection guide ($n = 16$) were evaluated by surgeons during mandibular reconstruction with ProPlan CMF.[2] Overall, 53% of the resection guides show "good" fitting with the observable small gaps between bone and guides ($n = 16$). The "very good" fitting with a perfect unambiguous fitting on the bone without any gaps ($n = 11$) on the mandible (37%). One "satisfactory" fitting with some larger gaps between the bone and plate (3%) is observed because of an unfavorable guide design in the area of the mandibular ramus. In two cases "poor" fitting is observed because the guides have no accurate fit on the bone. No correct position can be found at all in 7%.

The fit of the cutting guides on the donor bone grafts are also mostly rated as "good" (75%) and "very good" (13%). One "satisfactory" rating is referred to an iliac crest graft (6%). No cutting guide is used in one of the two scapula graft cases (6%) (►**Table 2**).[2]

Intraoperative Fitting of Patient-Specific Mandible Reconstruction Plate

The intraoperative fittings of patient-specific mandible reconstruction plates are evaluated ($n = 30$) by surgeons during mandibular reconstruction with ProPlan CMF. They find that the plates fitting with the mandibular stumps and bone grafts are mostly rated as "very good" fitting with perfect fit on the bone without any gaps (63%) or "good" fitting with small gaps between bone and plate (33%). One case is rated "satisfactory" with some larger gaps between bone and plate but acceptable (3%).[2]

Table 1 Overview of mandibular reconstruction studies using ProPlan CMF

Authors (publication year)	Study design	Type of reconstruction	No. of patients (the controls)
Wilde et al (2015)[2]	Prospective multicenter study	Primary and secondary	32
Ayoub et al (2014)[3]	Randomized prospective study	Primary and secondary	10 (10)
Zavattero et al (2015)[4]	Retrospective study	Primary	4
Zweifel et al (2015)[5]	Prospective study	Primary	9 (11)
Modabber et al (2014)[6]	Prospective study	Primary	4
Schepers et al (2015)[7]	Retrospective study	Primary	7
Succo et al (2015)[8]	Prospective study	Primary	5

Table 2 Evaluation of intraoperative fitting of cutting guide and resection guide by surgeons

Rating	Resection guide ($n = 30$)	Cutting guide ($n = 16$)
Very good[a]	11 (37%)	2 (13%)
Good	16 (53%)	12 (75%)
Satisfactory	1 (3%)	1 (6%)
Poor guide	2 (7%)	1 (6%)

Note: The information was reported by Wilde et al in 2015.[2]
[a]Very good means a perfect fitting on the bone without any gap; good, a good fitting with small gaps between bone and plate; satisfactory, some larger gaps between bone and plate. Guide positioning is difficult and not fully reproducible; poor guide, inaccurate fitting to the bone indicating that no correct position can be found.

Comparison of Operative Time with ProPlan CMF to That of Conventional Surgeries without Computer-Assist

Ayoub et al report the operative times of computer-assisted mandibular reconstruction with the vascularized iliac crest ($n = 10$) and conventional surgery without computer-assist ($n = 10$) on a randomized prospective clinical trial. The operative time from shaping the transplant at the donor site to the dissection of the pedicle in the computer-assisted surgery is significantly shorter than that of the conventional surgery (37.8 vs. 62 minutes, $p < 0.005$). Whereas, the time of shaping the transplant at the defect site in the computer-assisted surgery is significantly shorter than that of the conventional surgery (6.2 vs. 20.3 minutes, $p < 0.001$). The time of osteosynthesis of the transplant is significantly shorter than the computer-assisted surgery (10.1 vs. 18.2 minutes, $p < 0.005$). Although the ischemic time is significantly lower in the computer-assisted surgery compared with the conventional surgery (96.1 vs. 122.9 minutes, $p < 0.005$), the total operation time shows no significant difference between the two groups (498.5 vs. 525.2 minutes, $p = 0.527$).[3] Zweifel et al report the reconstruction time between the segmentation of fibula and osteosynthesis with ProPlan virtual planning and surgical guide with prebent reconstruction plate or patient-specific mandible reconstruction plates ($n = 9$) and that of conventional surgery with a free fibular flap and regular reconstruction plate ($n = 11$) on prospective study. They find that the mean time of 11 conventional freehand reconstructions was 88.2 minutes with a range of 60 to 110 minutes, whereas in the virtual planning and surgical guide cases, the mean time was only 20.8 minutes with a range of 14 to 34 minutes.[4] Whereas, Zavattero et al report that the mean ischemia time is 75 minutes and the mean operative time is 6 hours in four computer-assisted mandibular reconstruction with the free fibula flaps. The mean ischemia and operative times are similar to those of conventional surgical procedure.[5]

Accuracy of Virtual Plan

Modabber et al evaluate the accuracy of computer-assisted surgery in primary mandibular reconstruction with an iliac crest bone flap or an osteomyocutaneous fibula flap with the assist of ProPlan CMF. In iliac crest bone flap, the actual flap position shows the mean difference from the virtual plan is 2.43 mm. The surface deviation of less than 2 mm is seen in 39% cases, and the surface deviation of less than 1 mm is seen in 15% cases. Whereas a mean difference from the virtual plan is 2.18 mm, a surface deviation less than 2 mm is seen in 60% cases, and the surface deviation less than 1 mm is seen in 37% of the cases in the osteomyocutaneous fibula flap.[6] Schepers et al compare the postoperative positions of fibula flap, dental implants, and the virtual plan in seven mandibular reconstruction cases with patient-specific mandibular reconstruction plates, fibula grafts, and dental implants in a one-stage procedure with ProPlan CMF. The surgical outcome is compared with the virtual plan by superimposing on the mandible. For the fibula segments, the mean deviation is 3.0 mm, and the mean angulation is 4.2. For the implants, the mean deviation is 3.3 mm, and the mean angulation is 13.0.[7] Succo et al investigate the average difference between the virtual plan segment lengths and postoperative CT segment lengths in mandibular reconstruction with the fibular free flap with ProPlan CMF ($n = 5$), and find that the average difference is 0.98 ± 0.77 mm.[8]

Postoperative Condyle Position

Wilde et al evaluate the condyle head positions in the glenoid fossae in the preoperative panoramic X-ray with CT and postoperative X-ray with or without CT ($n = 30$). There are only two cases in which postoperative radiology shows a malposition of the condyle, including a case of previously existing malposition of the condyle compared with the preoperative position, whereas three cases of preoperative malposition of the condyle are restored to its radiological normal position.[2] Ayoub et al report that the comparison of the positions of the condyles before and after surgery in computer-assisted mandibular reconstruction with the vascularized iliac crests ($n = 10$) with those of conventional surgery without computer-assist ($n = 10$) on a randomized prospective clinical trial. In computer-assisted surgery, a significantly lower discrepancy in the intercondylar distance is observed than that of conventional surgery (1.3 vs. 5.5 mm, $p < 0.001$).[3]

Duration of Postoperative Intensive Care Unit and Hospitalization

Ayoub et al report the duration of postoperative intensive care unit and hospitalization in computer-assisted mandibular reconstruction with the vascularized iliac crests ($n = 10$) and that of conventional surgery without computer-assisted surgery ($n = 10$) on a randomized prospective clinical trial. Intensive care unit duration (2.0 vs. 2.1 days, $p = 0.894$) and postoperative hospitalization duration (17.5 vs. 19.1 days, $p = 0.683$) show no significant differences between the two groups.[3]

Cost for Virtual Planning Service with Surgical Guide

Zweifel et al compare additional cost including ProPlan CMF planning service, surgical guides, and prebent reconstruction plates or patient-specific mandible reconstruction plates for mandibular reconstruction with a free fibular flap ($n = 9$) with

Table 3 Calculation of residual cost of ProPlan CMF with prebent or patient-specific plate

Plate type	Prebent plate	Patient-specific plate
Cost	$5,098	$6,980
Calculated saved costs	$3,202	$3,202
Cost of regular recon plate	$665	$665
Residual cost	$1,232	$3,114

Source: Adapted from Zweifel et al 2015.[4]

those of conventional freehand technique with regular non-prebent reconstruction plates ($n = 11$). They find that the mean reconstruction times for segmentation of fibula, adaptation of plate, and osteosynthesis in 11 conventional reconstructions and the virtual planning cases are 88.2 and 20.8 minutes, respectively. The virtual planning and surgical guide cases can save 67.4 minutes. They calculate the institutional and personnel cost per minute of operation room time to be US$47.5. The total saved cost calculated by multiplying unit cost per minute ($47.5) with the saved time (67.4 minute) becomes $3,202 in the planning service and surgical guides group. Moreover, an individual regular reconstruction plate costs roughly $665. Virtual planning, surgical guides, and a prebent reconstruction plate cost around $5,098. Virtual planning, surgical guides, and a patient-specific mandible reconstruction plates cost around $6,980. They find that the additional costs of surgical guides with prebent plate, and patient-specific plate in virtual planning are $1,232 (ProPlan CMF with prebent plate $5,098—saved cost $3,202—regular plate cost $665 = $1,232) and $3,114 (ProPlan CMF with patient-specific plate $6,980—saved cost $3,202—regular plate cost $665 = $3,114), respectively (►**Table 3**).[4]

Discussion

The purpose of the mandible reconstruction is to improve the facial appearance and recovery of masticatory function. Moreover, the reconstructions of the symmetrical face and height of sufficient alveolar ridge are necessary. However, the finishes of the mandible reconstruction are often dependent on surgeons' experiences and skills. ProPlan CMF virtual planning service and surgical guide could improve the surgical results and reduce the reconstruction time. The authors found that currently a small number of reports exist regarding the mandibular reconstruction with virtual planning service and surgical guides. These reports also describe a small number of cases with short-term follow-up results, because the virtual planning service is a recent available service since 2011. In this situation, this review revealed that (1) mainly resection guides, cutting guides, and patient-specific mandible reconstruction plate were adequately fitted to the skeleton,[2] (2) the ischemic time might be more reduced than that of the conventional surgery,[3] (3) the accuracy of computer-assisted surgery in the mandibular reconstruction was clinically acceptable,[6–8] (4) condyle positions after the computer-assisted surgery was mainly normal.[2,3] On the other hand, there are still questions: (1) the utility of resection guide in carcinoma excision and (2) the affordability of the increased additional cost. The precise tumor resection along the surgical planning may decrease the recurrence rate of tumor. Moreover, the additional cost of virtual planning service and surgical guides is important problem, because health care systems always suffer from the pressure to reduce costs over the last decades.[4] Zweifel et al report that the saved cost calculated by multiplying the saved time with the unit cost per minute becomes approximately $3,200 in planning service and surgical guide group because of the shorter reconstruction time than that of conventional reconstruction. They find that the additional cost of virtual planning is reduced from approximately $5,100 to $1,200 with a prebent plate and from $7,000 to $3,100 for a patient-specific mandible plate.[4] However, they failed to discuss cost for the total operative time. Ayoub et al report that the time from shaping the transplant at the donor site to the dissection of the pedicle is significantly shorter in the conventional surgery than the computer-assisted surgery, whereas times of shaping the transplant and osteosynthesis at the defect site are significantly shorter in the computer-assisted surgery than the conventional surgery. Therefore, the total operative time shows no significant difference between the computer-assisted and conventional surgeries.[3] But that means that the time for shaping the nonperfused transplant is shorter, which is a significant advantage. A shorter time for raising the flap if not using a guide will, furthermore, always result in a larger donor-site defect, because reserves have to be preserved for grinding the transplant to the right shape. Zavattero et al also are unable to find a decrease in the mean operative time in free fibula flaps.[5] Seruya et al report that the reconstruction of the craniofacial skeleton, such as frontal bone, orbit, maxilla, or mandible are performed with a fibula free flap with ProPlan CMF ($n = 10$), and the ischemia time is significantly shorter in computer-aided group than the conventional group ($n = 58$) (120 vs. 170 minutes). Although both operative times are also shorter in the computer-aided group than the conventional group, there is no statistical significance between them (625 vs. 648 minutes, $p = 0.21$). Moreover, perioperative and long-term outcomes including (1) hospital time, (2) recipient-site infection, (3) partial and total flap losses, and (4) the rates of soft-tissue and bony tissue revisions are comparable in the two groups.[9] This review showed that there were no significant differences in (1) total operative time, (2) the intensive care unit duration, and (3) the postoperative hospital time between computer-assisted and the conventional surgeries.[3,5] This fact indicated that the use of virtual planning and surgical guides increased the costs of surgery, because other costs in surgery and hospitalization were comparable to those of conventional surgery. However, if long-term follow-up studies show that the complication rate, such as plate exposure and fracture, or tumor recurrence rate decrease more in the computer-assisted tumor resection and reconstruction than in conventional technique, computer-assisted surgery could be more cost-effective than conventional technique, because computer-assisted surgery gives a lower complication rate and lower recurrent rate, which reduce the necessity of the secondary surgery. The patient-specific mandible plate may contribute to the reduction of complications including plate fracture or exposure, because it is milled from titanium without requiring any bending processes, and the plate may be more stable and more resistant to fracture than conventional plate.[10] The prefabricated reconstruction plate with predefined holes in the transplant also allows the manipulation of the transplant with the plate fixed to it. This is convenient, as the transplant and its delicate vessels need not be touched during the fitting in process. The prefabricated plate will also allow to stretch a contracted scar-area to the desired length. Zavattero et al mention that there are two main advantages of the present virtual planning and surgical guides: (1) the preoperative model allows surgeons to plan the resection and reconstruction before surgery and (2) resection and reconstruction with the cutting guides and prebent plate allow the restoring of the complex structure of the resected bone to obtain a greater level of reconstructive accuracy. Therefore, this virtual planning service and surgical guides is discussed in selected cases in which complex reconstruction is required for reconstructing the large defects. Conventional methods might be preferable for cost-related reasons, when the resected area is small without the requirement of more than two osteotomies in the fibula free flap.[5]

Since this study reviewed mandibular reconstruction using only one CAD/CAM technology service, this study failed to reveal the difference between other mandibular reconstruction using CAD/CAM technologies and that using ProPlan CMF, and this will be the limitation of this study. In mandibular reconstruction (1) the height and width of neomandible is unable to fit those of the native remaining mandible, creating a step in the denture-bearing region,[11] but using either iliac crest or double-barrel fibula, the proper height can be achieved especially if 3D-planning is involved (►**Fig. 3**) and (2) secondary mandibular reconstruction[12] may have clinical problems. Secondary mandibular reconstruction is more difficult than primary reconstruction, because the mandibular segments are rotated and the soft-tissue cause contracture.[12] In these cases, 3D-planning allows rotation of the mandibular stumps into the right position and transplant-planning can be done on a corrected basis. These selected articles were mainly primary reconstructive cases. Secondary reconstructive cases were limited to be 12 cases. Ciocca et al report mandibular secondary reconstruction using the repositioning guide and bone plate by their CAD/CAM technology.[12] Hou et al report mandibular defect reconstruction using vascularized fibular osteomyocutaneous flaps with pre-shaped titanium mesh implant by their CAD/CAM technology for fitting the height and width of the native remaining mandible to those of transplanted bone.[13] Moreover, Zheng et al report the reconstruction of mandible using vascularized double-barrel fibula bone by their CAD/CAM technology.[14]

In conclusion, this review showed virtual planning service with surgical guides could provide a high quality of mandibular reconstruction. However, the higher additional cost than that of conventional technique is an issue. Evaluations of complications, tumor recurrence, and additional surgery in long-term follow-up will be necessary after surgery with the virtual planning service. The authors believe that this virtual planning service with surgical guides will be beneficial for patients and surgeons with better surgical outcomes. However, currently published reports are very limited due to a small number of cases and short-term follow-up. Large-scale and long-term follow-up studies are demanded.

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Competing Interests
None.

Ethical Approval
Not required.

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