

Economic analysis of a low-cost virtual surgical planning protocol for mandibular reconstruction: a case series

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Abstract

The aim of this study was to make an economic analysis and evaluation of a low-cost virtual surgical planning (VSP) protocol that was developed in house, and based on open-source software and a desktop 3-dimensional printer. All eight patients between April 2014 and 2015 who had been treated by mandibular reconstructions with microvascular fibular flaps that had been planned using the protocol were retrospectively analysed for accuracy, time, and cost. Median differences for planned compared with postoperative intercondylar distance, intergonial distance, and gonial angle did not differ significantly. A median (range) labour time of 85 (€57–124) minutes was needed. An evaluation of cost, including labour, showed an additional median (range) cost/patient of € 276 (€257.50–297.25). With the acquisition cost of the 3-dimensional printer omitted, there was a negligible additional cost/patient of €44.75 (€26.25–66). All planning was done by the junior surgeon and there was a steep learning curve. Our new VSP protocol is cost-effective, easy to use, and has an accuracy comparable with that of a standard VSP protocol. To the best of our knowledge this is the first report of an open-source software protocol in which the labour costs of the planning by a surgeon are included.

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Keywords: Mandibular reconstruction; Virtual surgical planning; 3D printing; Low-cost

Introduction

Virtual surgical planning (VSP) with patient-specific guides and reconstruction plates for mandibular reconstruction is well known, and several authors have reported its improved accuracy and superiority in reconstruction when compared with the freehand technique.^{1–5} However, it is associated with additional costs, which are a disadvantage in countries without reimbursement.⁶

We report an economic analysis of a new low-cost VSP protocol based on open-source software and a desktop 3-dimensional printer.

Patients, material, and methods

All patients who were treated by a virtually-planned mandibular reconstruction with microvascular fibular flap according to the low-cost protocol between April 2014 and April 2015 were retrospectively analysed (Table 1). A cost analysis was made to compare it with a VSP workflow provided by the industry.

The DICOM-derived images (slice thickness 0.75 mm) of a computed tomographic (CT) scan of the mandible and an angiographic CT of the fibula were segmented with a 3-dimensional slicer (open-source software, www.slicer.org). The resection of the affected mandible was virtually planned using Netfabb[®] Basic open-source software (Netfabb[®]) with resection margins based on the findings on magnetic resonance imaging (MRI). The fibula was cut virtually and

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Table 1
Patients' characteristics. Intercondylar, intergonial distance were measured (mm) before and after virtual surgical planning (VSP), as well as the gonial angle (°).

Patient and diagnosis	Planned reconstruction	Type of defect*	No. of fibular segments	Intercondylar distance		Intergonial distance		Gonial angle	
				VSP	Postoperatively	VSP	Postoperatively	VSP	Postoperatively
F, SCC		Class II	2	101.6	100.2	86.3	83.4	122.8	128.1
M, SCC		Class III	3	118.4	114.5	99.5	107.8	134.3	127.9
F, Adenoid Cystic Ca		Class I	2	101.8	99.1	85.4	84.0	128.4	132.1
M, SCC		Class I	1	104.6	106.0	92.7	91.6	131.7	133.8
F, SCC		Class I	1	101.3	101.1	83.2	82.8	130.3	134.2
F, Osteosarcoma		Class III	3	111.7	113.5	101.1	97.7	116.3	119.4
M, SCC		Class Ic	2	106.3	105.9	95.5	95.9	121.9	123.7
M, Ameloblastoma		Class I	1	119.8	124.1	96.9	101.1	126.9	128.3
Median			2	1.6	(p value:0.89)**	2.2	(p value:0.72)**	3.5	(p value:0.17)**
Min			1	0.2		0.4		1.4	
Max			3	4.3		8.3		6.4	

Abbreviation: SCC: spinocellular carcinoma; Ca = carcinoma; F: Female; M: Male.

* According to the classification of Brown et al.⁷.

** Paired *t*-test.

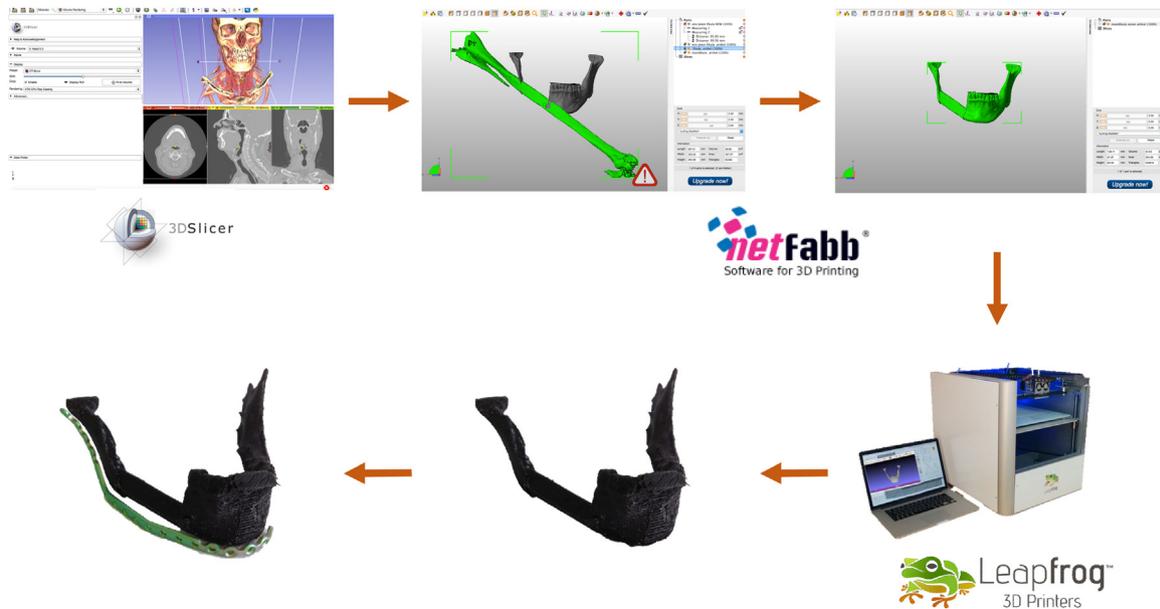


Fig. 1. Outline of the workflow. After segmentation of the DICOM data (3-dimensional slicer), resection of the affected mandible and reconstruction with a free fibular flap was planned in Netfabb[®] Basic open-source software. The virtually-planned reconstructed mandible was printed in polylactic acid (PLA) in a fused deposition modelling (FDM) desktop 3-dimensional printer (Leapfrog[®] Creatr), and a 2.0 mm ThreadLock TS[™] Smart reconstruction plate (KLS Martin) was pre-bent to its full length on to the 3-dimensional printed model.

segments were positioned according to the mandibular contour (Fig. 1). The angle of the fibular osteotomies and the length of the fibular segments were measured virtually. These measurements were used to transfer the digital plan into the operating theatre. The virtual reconstructed model was printed in three dimensions in polylactic acid (PLA) with a fused deposition modelling (FDM) desktop 3-dimensional printer (Leapfrog[™] Creatr) (Fig. 1).

A 2.0 mm ThreadLock[™] TS Smart reconstruction plate (KLS Martin[®]) was pre-bent to its full length on to the 3-dimensionally printed model, enabling adaptation at the time of operation in case the estimated resection margins had altered (Fig. 1). To assure accurate positioning of the reconstruction plate, drill holes for the locking osteosynthesis screws in the 3-dimensionally printed model were marked, and drill guides carrying anatomical landmarks based on the contour of the printed model were produced in-house with a light-cured composite (Primosplint Primotec[®]). The drill guide also functioned as a cutting guide, as the edge of the guide defined the resection plane.

The reconstruction plate was autoclaved at 134 °C for 18 minutes, and the guide was sterilised in a STERRAD[®] 100NX (Advanced Sterilization Products), a low-temperature gas plasma sterilisation technology.

During operation the guide was fixed with a 2.0 mm osteosynthesis screw into one of the drill holes of the guide. After resection of the affected mandibular segment, the reconstruction plate was positioned and fixed with locking screws into the pre-drilled holes on the proximal mandibular segments. Fibular osteotomies were made freehand using templates cut from a ruler according to the virtually-

calculated angles and lengths of the fibular segments. The fibular segments were positioned on to the reconstruction plate, with the pedicle still intact, and fixed with 2.0 mm locking screws.

The DICOM-derived images from a six-week postoperative CT scan were imported into iPlan 3.0.5 (Brainlab[®]). The intercondylar distance, intergonial distance, and gonial angle were measured on both the virtual planned mandible and the postoperative mandible, to ensure accuracy (Table 1). The time required for manufacture was recorded, and the cost of our protocol was analysed (Table 2). The accuracy was compared with systems described in current publications (Table 3).

Results

Eight patients were treated according to the protocol, with a male:female ratio of 3:5. Segmental mandibular resection and reconstruction was done to treat invasive squamous cell carcinoma (n = 5), ameloblastoma (n = 1), osteosarcoma (n = 1), and adenoid cystic carcinoma (n = 1). Resection of the affected part of the mandible resulted in Class I (n = 4), Class Ic (n = 1), Class II (n = 1) and Class III (n = 2) defects according to Brown et al (Table 1).⁷

The results of the analysis of accuracy are shown in Table 1. Evaluation of the difference in VSP and postoperative measurements resulted in a median (range) of 1.6 (0.2–4.4) mm for the intercondylar distance, 2.2 (0.4–8.3) mm for the intergonial distance, and 3.5° (1.4–6.4°) mm for the gonial angle. No significant differences were found (Table 1).

Table 2
Manufacturing time and cost analysis.

Case No.	Segmentation	Planning	Reconstruction	Cutting/ drill		Total labour		3-dimensional		Total cost (€)		
	Time (min)	Time (min)	Time (min)	Time (min)	Cost (€)	Time (min)	Cost (€)	Time (min)	Cost (€)	Labour + guides + 3- dimensional print	+3- dimensional printer	+Recon plate
1	25	40	35	13	20	113	28.25	267	4	52.25	283.50	1033.50
2	21	53	31	19	30	124	31	272	5	66	297.25	1047.25
3	18	34	28	11	20	91	22.75	266	3.5	46.25	277.50	1027.50
4	15	25	20	9	10	69	17.25	261	2.5	29.75	261	1011
5	20	21	16	8	10	65	16.25	262	3	29.25	260.50	1010.50
6	16	48	15	17	30	96	24	270	4.5	58.50	289.75	1038.75
7	19	33	13	14	20	79	19.75	268	3.5	43.25	274.50	1024.50
8	17	18	12	10	10	57	14.25	262	2	26.25	257.50	1007.50
Median (range)	18.5 (15-25)	33.5 (18-53)	18 (12-35)	12 (8-19)	20 (10-30)	85 (57-124)	21.25 (14.25-31)	266.5 (261-272)	3.5 (2-5)	44.75 (26.25-66)	276 (257.5-297.25)	1026 (1007.5-1047.25)

Table 3

Median values for difference in intercondylar, intergonial distance (data in mm) and gonial angle (data in °) measurements between virtual surgical planning and postoperative, compared with current publications.

First author and reference	Median (range)
Intercondylar distance:	
Foley ¹	2.4 (1.9-4.5)
Mascha ³	2.87 (0.7-3.9)
Weitz ⁵	–
Spaas (current paper)	1.6 (0.2-4.4)
Intergonial distance:	
Foley ¹	–
Mascha ³	0.82 (0.2-2.6)
Weitz ⁵	–
Spaas (current paper)	2.2 (0.4-8.3)
Gonial angle:	
Foley ¹	2.8 (0.4-4.5)
Mascha ³	–
Weitz ⁵	4.5 (0-18)
Spaas (current paper)	3.5 (1.4-6.4)

A time and cost analysis of our protocol is given in Table 2. The time analysis showed that a median (range) time of 18.5 (15-25) minutes was needed to segment the native mandible and fibula, and 33.5 (18-53) minutes to plan the fibular osteotomies. Pre-bending of the reconstruction plate took 18 (12-35) minutes because of the previously pre-bent shape of the ThreadLock™ TS Smart reconstruction plate (KLS Martin®). The moulding of the light-cured composite, and marking the drill hole, took a median (range) of 12 (8-19) minutes. In total, a median of 352 (319-396) minutes was required to plan a case, with 266.5 (261-272) minutes of 3-dimensional printing. The actual planning and laboratory work was completed within 85 (57-124) minutes by the junior surgeon under the supervision of the senior surgeon. The labour cost of a junior surgeon in Belgium is €15.24/hour, which leads to a median (range) labour cost of €21.25 (€14.25-31.00) for our workflow. The median (range) cost of the entire protocol, including the reconstruction plate, was €1026 (€1007.50-1047.25). In the Belgian financial system, the reconstruction plate is reimbursed and, therefore, the median (range) additional cost to the patient would be €276 (€257.50-297.25).

A conventional VSP protocol with a patient-specific milled reconstruction plate (as offered by the industry to our department) cost about €3500 with 12 days for manufacturing and delivery.

Discussion

VSP is well integrated nowadays because of its confirmed accuracy and superiority in reconstruction.¹⁻⁵ Our accuracy analysis resulted in a median (range) of 1.6 (0.2-4.4) mm for the intercondylar distance, 2.2 (0.4-8.3) mm for the intergonial distance, and 3.5° (1.4-6.4°) for the gonial angle. These results are in agreement with the published data on conventional VSP (Table 3).^{1,3,5} Foley et al reported a median

(range) of 2.4 (1.9-4.5) mm for intercondylar distance and of 2.8 (0.4-4.8) mm for intergonial distance.¹ The accuracy analysis of a conventional VSP protocol by Mascha et al resulted in a median (range) of 2.87 (0.7-3.9) mm for intercondylar distance and 0.82° (0.2-2.6°) for the gonial angle.³ Weitz et al concluded that conventional VSP resulted in a median (range) of 4.5° (0-18°) for the difference in gonial angle.⁵ We can state that our low-cost protocol has an accuracy comparable to that of a conventional VSP workflow offered by the industry but without the use of virtually planned fibular cutting guides.

VSP reduces operative time and ischaemic time, which results in a cost saving in the median running cost/minute of theatre time.⁶ Nonetheless, there is still an additional cost for using a VSP protocol, either with pre-bent or milled plates. This is justified by its superior accuracy, which results in more bony contact between the fibular segments, a superior aesthetic outcome that is attributable to preoperative planning and, therefore, a better functional outcome in the end.⁶ However, in some capped health care systems, such as the one in Belgium, this additional cost is charged to the patient. Several authors have previously reported various protocols, based on open-source software, to reduce this additional cost.⁸⁻¹¹

Dell'Aversana Orabona et al described a workflow based only on open-source software.⁸ They mentioned an additional cost of €3/cutting guide, with the acquisition cost of the 3-dimensional printer being excluded, and a virtual planning time of three hours. They required a certain learning curve to familiarise themselves with the software, which was used by a surgeon. The cost of the reconstruction plate and labour was not calculated.

Dupret-Bories et al used open-source software exclusively in their protocol, but handling was done by an engineer.⁹ Their protocol resulted in a median of five days' production time and an additional cost of €1000/patient.

Bosc et al reported a protocol based on a combination of open-source and commercial software packages.¹⁰ They achieved a median manufacturing time of five days and an additional cost of €989/patient. The software was easy to use by the surgeon.

Ganry et al developed an open-source software protocol in which the 3-dimensional modelling was done by the surgeon.¹¹ A median of seven days was needed, at an additional cost of €100. The cost of the time spent by the surgeon was not taken into account. The open-source software package (Blender) required additional training and a learning curve, which was time-consuming, particularly when the planning is done by a surgeon instead of a clinical engineer.

The main advantages of our protocol are its low additional cost, time efficiency, and ease of use. The main disadvantage is the non-use of virtual planned fibular cutting guides, but this seems to have no influence on the accuracy of the outcome of the reconstruction (Table 3). The open-source software packages used in our protocol, namely the 3-dimensional slicer and Netfabb® Basic, are autodidactic with steep learn-

ing curves, but they can easily be mastered by a surgeon. The planning, printing, and laboratory time took almost six hours in total. When the time needed for sterilisation is added, our protocol involves a one-day workflow. A median (range) additional cost of € 276 (257.50–297.25) /patient is necessary, but this is the lowest yet to be reported. If the acquisition cost of the 3-dimensional printer is omitted from the calculation, the median (range) additional cost/patient can be further reduced to a negligible amount of €44.75 (26.25–66.00).

Conclusion

We conclude that our protocol is cost-effective, easy to use, and has the advantages and accuracy of a conventional VSP protocol. In capped health care systems, such as the Belgian one, low-cost VSP protocols are of additional value. To the best of our knowledge this is the first report of an open-source software protocol in which the labour costs of the planning by a surgeon are included.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients' permission

Ethics approval not required. Patients signed informed consent for publication of their anonymised data.

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