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Virtual planning and 3D-printed guides for mandibular reconstruction: Factors impacting accuracy

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Abstract

Objectives: Examine accuracy and factors impacting accuracy for mandibular reconstruction with virtual surgical planning, 3D printed osteotomy guides and preoperatively bent mandibular reconstruction plate (VSP/3Dprinted-guide/plate).

Method: Retrospective review of osseous-free-flap mandibular reconstructions with VSP/3Dprinted-guide/plate between January 2015 and July 2020 at a single academic medical center.

Patient demographics, disease, and treatment variables were extracted. Accuracy was assessed by 3D-model-overlay with cephalometric and donor-bone segment length measurements. Multivariate analyses were performed to determine factors impacting cephalometric accuracy.

Results: 60 cases met criteria: 41 (68%) cancer, 14 (23%) osteoradionecrosis (ORN), 5 (8%) secondary mandibular reconstruction. Thirteen cases (22%) were Brown class III or IV. Thirty-nine cases (65%) had ≥2 flap bone segments. Average donor-bone length was 82 mm (SD: 28). 3D-model-overlay accuracy demonstrated minimal deviation between planned and actual reconstruction: intercondylar distance = 2.10 mm (SD: 2.2); intergonial distance = 2.23 mm (SD: 1.9); anterior–posterior distance (APD) = 1.76 mm (SD: 1.5); gonial angle (GA) = 3.11 degrees (SD: 2.4). Mean change in donor-bone segment length inferiorly was 2.67 mm (SD: 2.6) and superiorly 3.27 mm (SD: 3.2). Higher number of donor-bone segments was associated with decreased accuracy in GA ($p = .023$) and longer donor-bone length was associated with decreased accuracy in APD ($p = .031$).

Conclusion: To our knowledge this is the largest series assessing surgical accuracy of VSP/3Dprinted-guide/plate for osseous-free-flap mandibular reconstruction. We demonstrate highly accurate results, with increased number of donor-bone segments

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and donor-bone length associated with decreased accuracy. Our findings further support VSP/3Dprinted-guide/plate as a reliable and accurate tool for mandibular reconstruction.

Level of Evidence: Level 4.

KEYWORDS

3D printing, computer aided design, computer aided manufacturing, cutting guides, fibula free flap, mandibular reconstruction, pre-bent plate, virtual surgical planning

1 | INTRODUCTION

Mandibular reconstruction remains one of the most challenging areas of head and neck surgery. Cosmetic and functional considerations, including maintenance of occlusion, necessitate a high degree of accuracy as the mandible is rebuilt. Many sources of bone have been used, including fibula, Iliac crest, scapula and radial forearm. The fibula free flap, as first described by Hidalgo in 1989,[1] has become the free flap of choice. It provides a long, vascularized segment of bone that can be osteotomized to match the curved contour of the native mandible and can be harvested with a skin paddle for mucosal or skin repair. The greatest challenges have been the intraoperative sculpting of the bone graft to precisely match the mandibular defect and aligning the graft to maximize approximation of bone edges and optimize bone healing.[2–5]

A paradigm shift in mandibular reconstruction has been the integration of computer-aided-design and manufacturing into the surgical process as described by Hirsch et al. in 2009.[2] Virtual surgical planning (VSP) shifts the decision making and creative mandibular sculpting process into the preoperative period. The resulting 3D-printed osteotomy guides and pre-bent mandibular reconstruction plate permit the planned surgery to be executed in the operating room with great precision and ease. These techniques decrease operative time[4,6–13] and facilitate surgical training.[14–16]

Beyond demonstrating a new technique is workable and has practical potential, a critical step in the proof of concept is determining its accuracy. Preoperative VSP provides a framework for determining accuracy via comparison of planned versus actual surgical results. 3D-model-overlay, with cephalometric measurements (intercondylar distance, intergonial distance, anterior–posterior distance, and gonial angle) of planned and executed mandibular reconstruction, can be used to assess the accuracy of reconstruction.[6,14,17–19] There have been more limited studies assessing the accuracy of mandibular reconstruction with VSP and 3D printing.[6,13,14,17,18,20–23] To the best of our knowledge, this is the largest case series assessing accuracy. Computing accuracy furthermore permits analysis of factors that might adversely impact accuracy, leading to greater understanding and anticipation of operatively challenging cases.

This study aims to analyze accuracy and factors impacting accuracy from a large, single institution, case series of 3D-aided mandibular reconstructions.

2 | MATERIALS AND METHODS

2.1 | Study design and subjects

All patients who underwent osseous-free-flap mandibular reconstruction aided by VSP/3Dprinted-guide/plate between January 2015 and July 2020 at our tertiary care center were included in the study. A retrospective review of patient records was approved by our institutional review board.

Patient demographics including age, sex, and tobacco use were recorded. The indication for mandible reconstruction was noted. Prior head and neck oral cavity surgery, preoperative mandibular fracture and neoadjuvant treatments were noted.

Operative ablative details were reviewed. The Brown classification for mandibular defects was applied to the operative defect.[24] Reconstructive details were reviewed including length of donor-bone and number of bone segments. Deviations from the VSP were recorded. Major deviations were defined as any adjustment in position of mandible or donor-bone osteotomy guides. Minor deviations included unplanned burring, use of marrow paste or changes to the pre-bent plate.

Postoperative complications were recorded including any need for return to the operating room (RTOR); any primary (mandibular region) or neck infection or dehiscence or orocutaneous fistula; and any donor site complications. New onset outpatient complications were similarly recorded. Removal of mandibular hardware was noted. Need for adjuvant therapy was recorded.

2.2 | Virtual surgical planning and 3D fabrication of surgical templates

All patients had fine-cut CT of the mandible. Patients undergoing fibula free flap reconstruction underwent preoperative peripheral vascular assessment. In the early years this was done with magnetic resonance angiography and later cases were assessed with CT angiography. Likewise, in the early years stock CT fibula was used for VSP and in later years fibula or iliac crest CT was obtained, allowing patient specific donor-bone planning. The CT scan was saved as a DICOM file (Digital Imaging and Communications in Medicine), segmented and converted to a virtual 3D-model Stereolithography (STL) file format. The reconstructive surgeon had a web-based conference with the clinical engineer (from Materialize) and utilized interactive 3D-models of mandible and donor bone to perform virtual mandibulectomy and reconstruction of the planned mandibular defect using Proplan CMF software (Materialize, Leuven, Belgium). Cases with significant mandibular distortion from tumor, fracture or absent mandible segments were modeled based on the unaffected mandible using mirror image principle.[9,13,23] Design of the osteotomy guides was done in 3-Matic software (Materialize). The positioning and shape of mandible osteotomy guides were determined, being mindful of the soft tissue pocket and adjacent anatomy. The patient's peripheral vascular status, mandibular defect, soft tissue defect and anticipated status of neck vessels were used to plan the side of the donor-bone graft. The donor-bone length, number of segments and position of osteotomies were determined. Osteotomies were fashioned to optimize bone apposition with the recipient mandibular remnants. The osteotomy guides were 3D-printed in polyamide with Magics (Materialize). 3D-printed stereolithographic resin models of the planned reconstructed mandible were made. Preoperatively, the 2.0 mm locking titanium mandibular reconstruction plate was either manually bent to fit the planned reconstructed mandibular resin model or 3D-milled from a block of titanium via a subtractive manufacturing method, PSPM (DePuy Synthes, West Chester, PA).

2.3 | Technique: surgical procedure

Surgery was accomplished by a two-team approach. Most surgeries were performed by the two senior surgeons LAG and DJA. Segmental mandibulectomy was performed utilizing the mandibular osteotomy guides. Fibula free flap harvest was performed as described by Hidalgo.[1] The osteotomized bone flap was affixed to the mandible with the aid of the pre-bent mandibular reconstruction plate. Donor and neck vessels were anastomosed, then mucosal and skin closures were performed.

2.4 | Accuracy analysis

Postoperative CTs, performed before adjuvant radiation therapy when possible, were used for the 3D-model-overlay accuracy analysis. The postoperative CT was converted and reformatted into a 3D-STL-model and was overlayed with the virtually planned 3D-STL-model, registering the condyles as anchor points (software, Mimics 24.0 and 3-matic 16.0, Materialize). A single clinical engineer from Materialize performed all linear measurements. Deviations between planned and actual mandibular reconstruction in cephalometric measurements were recorded as described by Zhang et al.[18] including: intercondylar distance (ICD), intergonial distance (IGD, distance between both angles), anterior–posterior distance (APD, distance of the perpendicular section measured between the symphysis and the intercondylar line), and gonial angle (GA). The change in planned versus executed donor-bone segment length along the lateral-superior and lateral-inferior aspect of each donor bone segment was also recorded (Figures 1 and 2).

2.5 | Data analysis: Factors impacting accuracy

2.5.1 | Statistics

Univariable and multivariable analyses were done to assess for factors associated with increased change between planned and actual reconstruction among the four cephalometric measurements: ICD, IGD, APD, and GA. A two-sided p value <.05 was considered statistically significant. All analyses were conducted using R version 4.1.0.

3 | RESULTS

Between January 2015 and July 2020, there were 70 cases (69 patients) of osseous-free-flap mandibular reconstruction aided by VSP/3Dprinted-guide/plate. One patient underwent 2 fibular free flap reconstructions for right and later left mandibular osteoradionecrosis (ORN). Ten cases were eliminated from the study: 1 case had fibula free flap failure and alternate reconstruction; 7 cases did not have post-operative CT for accuracy analysis; 2 cases had intraoperative major deviations from the virtual surgical plan due to excess radiation fibrosis of the soft tissue pocket, necessitating reduction in donor-bone length and deliberate underprojection of the mandible. The remaining 60 cases (59 patients) were included.

Patient characteristics are reported in Table 1. Forty-one cases (68%) were new/recurrent cancer, 14 (23%) ORN and 5 (8%) secondary mandibular reconstruction (prior segmental resection and no reconstruction or failed reconstruction).

Operative results are reported in Table 2. The Brown classification of mandibular defect[24] was class 2 or higher in 24 cases (40%). There was only one case with a non-fibula free flap reconstruction due to peripheral vascular disease, instead using an iliac crest internal oblique free flap. Patient-specific CT donor-bone was used for VSP for 25 cases (24 fibula and one iliac crest) and generic stock fibula CT was used for 35 cases. Four patients had 3D-printed custom milled plates; the remainder had pre-bent plates. The average donor-bone length was 82 mm and 39 cases (65%) had ≥2 bone segments. Major intraoperative modification from the VSP occurred in 8 cases (13%) and minor modification in 8 (13%).

The reasons for the 8 major modifications--adjustment in placement of fibula and/or mandibular osteotomy guide, thereby altering amount of bone resection--were as follows: 5 patients needed more mandibular bone resected to optimize cancer margins, requiring additional analogous increase in fibula resection; 3 patients had intraoperative suboptimal occlusion, requiring adjustments in donor-bone length to attain class I occlusion.

The average length of hospital stay was 12 days (SD: 5.2, range 6–34 days). Postoperative complications are reported in Table 3. The mean follow-up was 91 weeks (SD: 73, range 10–290 weeks).

Among the 41 cancer patients, adjuvant treatment included: chemoradiation (20 patients), radiotherapy alone (17 patients, including 5 patients undergoing re-irradiation), and adjuvant immunotherapy (4 patients). Nine patients declined advised chemotherapy; one patient declined advised radiotherapy.

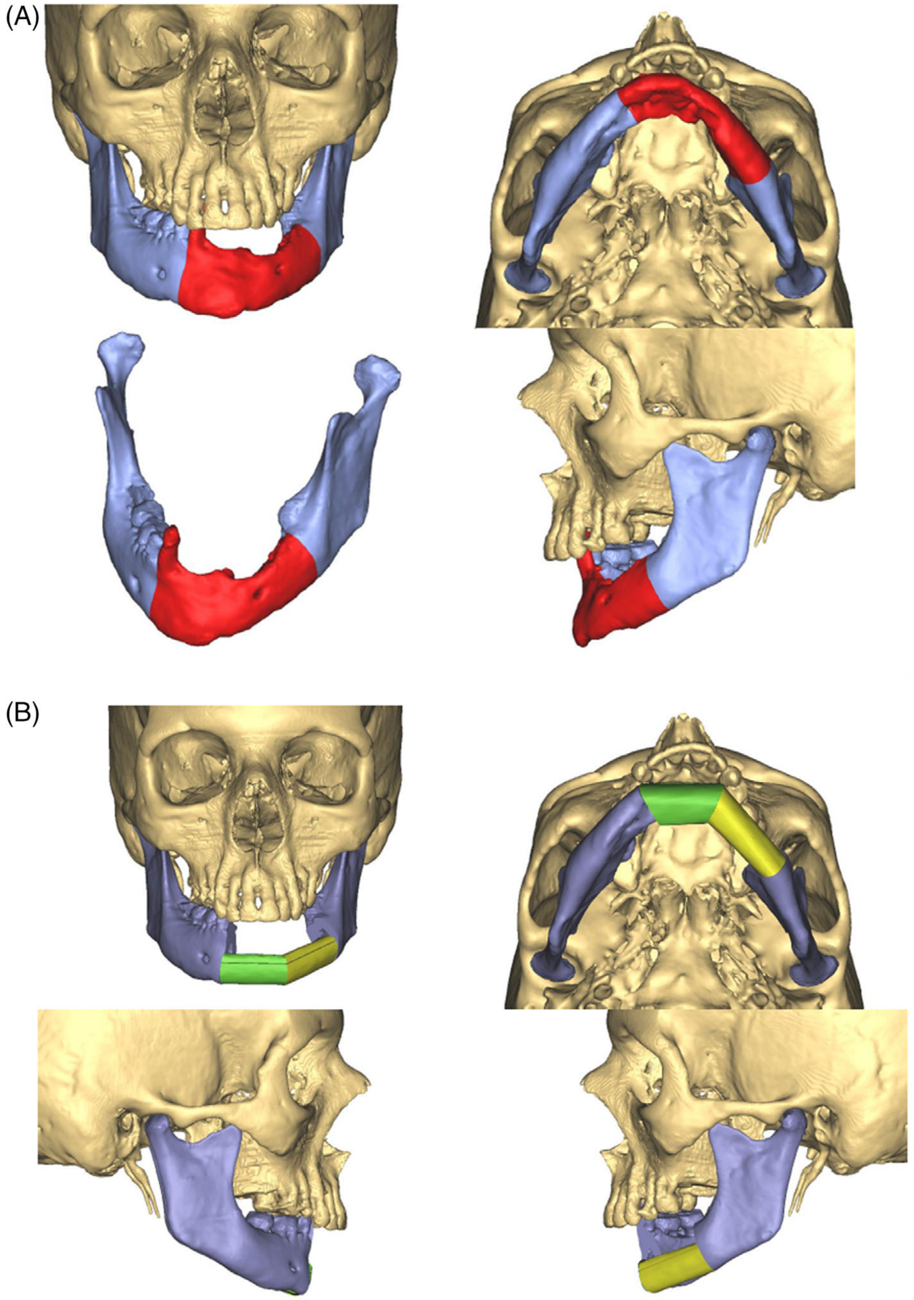

FIGURE 1 (A) Preoperative 3D Model, patient with T4 SCCA left mandibular alveolar ridge (planned resection in red). (B) Virtual Surgical planning with 2 segment fibular free flap reconstruction (in green and yellow).

The mean timing of postoperative CT used for overlay accuracy was 41 weeks (SD: 40, range 0.3–225 weeks). The CT slice width was ≤2 mm (31 cases), 2.1–3 mm (26 cases), and 3.75 mm (3 cases).

The results from the pre- and post-3D-model-overlay accuracy cephalometric analysis are reported in Table 4. Accuracy results related to the length of donor-bone segments are reported in Table 5. The findings were highly accurate with only a 1.8–3.5 mm difference between planned versus actual reconstruction among all parameters.

Factors assessed on univariable and multivariable analyses for their association with increased change between planned and actual reconstruction (indicative of decreased accuracy) in four cephalometric measurements (ICD, IGD, APD, GA) included: prior head and neck cancer, prior oral cavity surgery, prior radiotherapy, new or recurrent cancer, ORN, Brown classification (Brown class 1 & 2 vs. Brown class 3, 4 & 1c), number of donor-bone segments (1 vs. ≥2 segments), donor-bone length (continuous variable), and intraoperative major or minor modification to the VSP. On univariable analysis, longer donor-bone length was significantly associated with greater change (decreased accuracy) in APD (estimate = 0.02, 95% CI = [0.00, 0.03], $p = .007$), and ≥2 donor bone segments was significantly associated with greater change in GA (estimate = 1.7, 95% CI = [0.44, 2.9], $p = .008$). The other factors were not significant.

On multivariable analysis, associations between longer donor-bone and less accurate APD (estimate = 0.02, 95% CI = [0.00, 0.04], $p = .031$) and ≥2 donor bone segments and less accurate GA (estimate = 1.88, 95% CI = [0.28, 3.49], $p = .023$) remained significant.

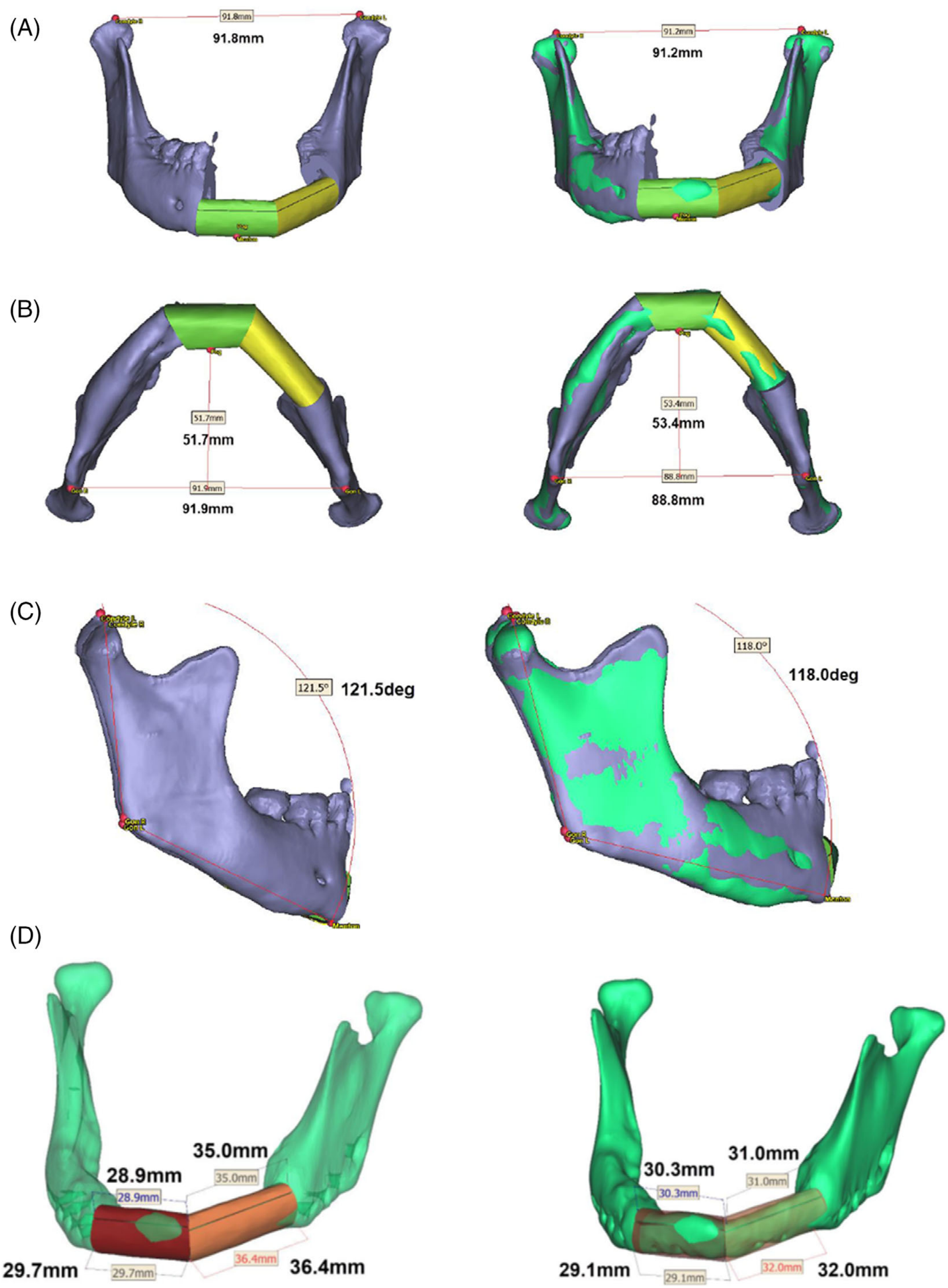

FIGURE 2 Postop 3D overlay accuracy analysis with four cephalometric measurements – virtual surgical plan left, actual with overlay right. (A) Intercondylar distance: planned 91.8 mm left, actual 91.2 mm right. (B) Intergonial distance: planned 91.9 mm, actual 88.8 mm. Anterior Posterior Distance: planned 51.7 mm, actual 53.4 mm. (C) Gonial angle: planned 121.5 degrees, actual 118 degrees. (D) Fibula segment lengths: planned and actual superior and inferior segment lengths.

4 | DISCUSSION

In this single institute, retrospective cohort study, we sought to report reconstruction accuracy findings for patients undergoing mandibular reconstruction aided by VSP/3Dprinted-guide/plate and to identify factors associated with less accurate results. In this large case series, we found a high level of accuracy with average deviation from virtual plan of 1.76, 2.10, and 2.23 mm among cephalometric measurements for anterior–posterior, intercondylar and intergonial distances and 3.11 degrees for gonial angle. Not surprisingly, higher number of

TABLE 1 Patient characteristics

	No. (%); $n = 60$
Sex	
Male	39 (65%)
Female	21 (35%)
Age (years)	
Mean	65
Range	49–83
Habits, medical history, preoperative exam	
Tobacco smoking ≥10 years	28 (47%)
Prior H&N SCCA	26 (43%)
Prior oral cavity surgery	20 (33%)
Prior H&N radiation therapy	23 (38%)
Prior >1 courses of RT	7 (12%)
Preoperative mandibular fracture	13 (22%)
Indications for mandibular reconstruction	
Osteoradionecrosis	14 (23%)
Secondary reconstruction[a]	5 (8%)
New or recurrent SCCA	41 (68%)
Dominant primary location	$n = 41$
Mandibular alveolar ridge	24 (59%)
Floor of mouth	7 (17%)
Retromolar trigone	7 (17%)
Buccal	2 (5%)
Neck abutting mandible	1 (2%)
Neoadjuvant immunotherapy	11
Neoadjuvant chemotherapy	4
SCCA Pathology Stage (AJCC 8th ed.)	$n = 41$
T0	1 (2%)
T1	2 (5%)
T2	2 (5%)
T3	4 (10%)
T4	32 (78%)
T4a	24
T4b	8
Stage 0[b]	1 (2%)
Stage I[b]	2 (5%)
Stage II[b]	1 (2%)
Stage III[b]	4 (10%)
Stage IV	33 (80%)
IVA	19
IVB	14

[a]Absent mandible due to prior mandible resection or failed reconstruction.
[b]All of Stage 0, I and II and three of Stage III cases had neoadjuvant immunotherapy with one case neoadjuvant immunotherapy and chemotherapy.

donor-bone segments and longer donor-bone length, both indicators of more complex reconstruction, were significantly associated with decreased accuracy.

TABLE 2 Operative results

	No. (%), $n = 60$
Brown classification of mandibular defect[24]	
1 (lateral without canine)	34 (57)
1c (and condyle)	2 (3)
2 (lateral with canine)	11 (18)
3 (anterior with both canines)	10 (17)
4 (anterior both canines & lateral)	3 (5)
Donor-bone length, mean	82 mm (SD: 28)
Number of donor-bone segments	
1	21 (35)
2	32 (53)
3	7 (12)
Intraoperative modifications from virtual surgical plan	
Major modifications[a]	8 (13)
Minor modifications[b]	8 (13)

[a]Major modification = change in position of osteotomy guides.
[b]Minor modification = unplanned burring, marrow paste or bending plate.

TABLE 3 Postoperative complications

	No. (%), $n = 60$
Inpatient	
Return to operating room	8 (13)
Vessel revision/exploration	3
Hematoma	3
Revision occlusion	1
Retained drain	1
Minor primary or neck infection or dehiscence	13 (22)
Orocutaneous fistula	2 (15)
Donor site complication	5 (38)
Outpatient new/delayed complications	
Minor primary or neck infection or dehiscence	21 (35)
Orocutaneous fistula	2 (3)
Donor site complications	11 (18)
Return to operating room[a]	16 (27)
Hardware removal	9
Minor Flap secondary revision	6
Neck infection	2
Donor dehiscence	1
Closure tracheocutaneous fistula	1

[a]Outpatient complications RTOR – 3 cases RTOR for more than one complication.

Comparison of accuracy results among studies is challenging due heterogenous patient populations, lack of uniformity in mandibular defect classification and varying methods of accuracy analysis. We utilized the Brown classification of mandibular defects first described in 2016[24] and employed by others.[25,26] The Brown system is based on four corners representing change in mandible form and need for graft osteotomies. Classes I-IV reflect increasing defect size, increasing number of osteotomies and thereby increasing complexity of reconstruction. Application of the classification system is logical, simple, and both clinically and operatively relevant.

TABLE 4 Accuracy: Pre and postoperative 3D-model-overlay with cephalometric measurements

Measurement	Mean change, mm, planned compared to post (SD)
Intercondylar distance (mm)	2.10 (2.2)
Intergonial distance (mm)	2.23 (1.9)
Anterior–posterior distance (mm)	1.76 (1.5)
Gonial angle (degrees)	3.11 (2.4)

TABLE 5 Accuracy: Pre and postoperative 3D-model-overlay with donor-bone segment lengths

Segment	Mean change superior length,[a] mm (SD)	Mean change inf length,[b] mm (SD)
Fibula 1 ($N = 60$)	3.19 (3.0)	3.48 (3.6)
Fibula 2 ($n = 32$)	2.04 (1.8)	2.92 (2.3)
Fibula 3 ($n = 7$)	1.86 (1.8)	3.33 (3.1)
Total mean change	2.67 (2.6)	3.27 (3.2)

[a]Superior length measured along superior lateral aspect of donor bone segment.
[b]Inferior length measured along inferior lateral aspect of donor bone segment.

Beyond patient and surgical variables, numerous logistical and technical sources can contribute to reconstructive inaccuracy. Technical considerations include image acquisition, image segmentation from 2D-CT into a virtual 3D-model in STL file format, and method of accuracy assessment. Van Baar[25] advises obtaining CT from the same machine pre and post reconstruction, with <1.25 mm slice thickness and post reconstruction CT within 6 weeks of surgery or prior to adjuvant radiotherapy. Van Baar's[27] systematic review found the most common accuracy assessment utilized Proplan/Surgicase CMF VSP software with overlay of pre and post-operative STL models with condyle as landmark.

For accuracy analysis, we furthermore propose measurement of deviation in four cephalometric parameters (intercondylar distance, intergonial distance, anterior–posterior distance and gonial angle). Other studies have similarly used cephalometric parameters to measure accuracy[6,7,14,17,28] with the condyle as anchor.[17,27,29,30] We chose these cephalometric measurements because they assess morphologic restoration of projection, symmetry and angles.[19] These measurements are anatomical landmarks that are easily recognizable and reproducible for clinicians.[31]

Additional appreciation of accuracy can be gained by comparing planned versus actual length of donor-bone segments.[13,18,19,28,32] Guesens[32] advocates measuring both superiorly and inferiorly along the lateral aspect of mandible. Blanc[19] and Zang[18] additionally propose measuring displacement or angular deviation of donor-bone segments. Table 6 compares our accuracy results to others utilizing 3D-model-overlay with cephalometric measurements and donor-bone length measurements. Our large series demonstrates excellent accuracy when compared to others, despite having limited exclusions.

To our knowledge, we are the first to report patient characteristics and operative factors impacting accuracy using 3D-overlay-models with cephalometric measurements. On multivariate analysis,

TABLE 6 Comparison of mandibular reconstruction accuracy studies – 3D model overlay deviation between planned and actual reconstruction with cephalometric measurements and donor-bone lengths

Author, year	*n*	Intercondylar distance (mm)	Intergonial distance (mm)	Anterior posterior distance (mm)	Gonial angle (degrees)	Donor-bone length (mm)	Exclusions
Annino et al.	60	2.10	2.23	1.76	3.11	Superior 2.36 Inferior 3.24	Deliberate intraoperative underprojection due to stiff soft tissue pocket
Blanc et al., 2019[19]	13	3	2	1	5	Inferior 2	≤1 fibula segment
Goormans et al., 2019[17]	26	3.86	3.14	2.92		1.78	CT >1 mm CT >3 months post-op Any intraoperative changes to virtual surgical plan
Saini et al., 2019[20]	10	NA	2.43	0.87	2.37	NA	Edentulous Follow up <3 months
Ren et al., 2018[6]	15	2.92	2.93	4.31	3.85	NA	Unstable occlusion ≤ 1 fibula segment
Zhang et al., 2016[18]	8	2.97	2.96	4.27	3.22	1.34	Condyle resection (only benign disease included)
Foley et al., 2013[14]	5	2.7	2.5	0.9	NA	NA	None

Abbreviation: NA, not available.

greater number of donor-bone segments and increased length of donor-bone were significantly associated with decreased accuracy. This makes intuitive sense because these variables represent larger defects and more complex reconstructions. Knowing that defects requiring longer fibula length or multiple segments are associated with less accurate results can help the surgeon council the patient regarding risk. The surgeon can anticipate greater difficulty in the operating room and pay particular attention with angles and wedge osteotomies. These findings might initiate future innovation and improvements in virtual surgical planning and cutting guides. Our sample size and heterogeneity limited the ability to assess the relevance of smaller subgroups anticipated to likely yield less accurate results, such as preoperative mandibular fracture, preoperative malocclusion/jaw malalignment, prior mandibular surgery, prior oral cavity free flap and cases undergoing secondary reconstruction.

The benefits from VSP/3Dprinted-guide/plate reconstruction include increased efficiency, reproducibility and improved accuracy. Yet the gains must be weighed against the added cost. The added commercial costs for VSP/3Dprinted-guide/plate have been reported at $4000[8] with costs substantially reduced if portions of the process are done in house.[26] Efficiency gains in operative time have ranged between 80–88 min,[7,19] and gains in ischemic time have ranged between 36–50 min.[18,19] The decreased operating room time expense has been found to offset the added cost related to VSP and the 3D printing process.[8,12,33] Additionally, as VSP/3Dprinted-guide/plate use expands, costs should decrease, and insurance reimbursements should improve.[34]

One of the greatest benefits from VSP/3Dprinted-guide/plate reconstruction is the ease of reproducing the precise plan in the operating room. The learning curve for traditional free hand fibula sculpting and plate bending is long, with results varying between surgeons according to experience and technical skills.[35] VSP with guides flattens the learning curve and increases proficiency and accuracy.[14,19] The results are reproducible with similar outcomes for surgeons of varying level of experience, benefiting the less experienced surgeon.[15] VSP/3Dprinted-guide/plate reconstruction has been evolving toward becoming the criterion or mainstay in mandible reconstruction.[5,8,36,37] The high level of accuracy, compared to planned modeling, shown in this study, helps solidify VSP/3Dprinted-guide/plate reconstruction's place among the new opportunities in personalized medicine.

Current and future directions in mandibular reconstruction include revisions and enhancements to the preoperative surgical planning and intraoperative execution, and utilization of in-house surgical planning labs. For example, machine learning can be applied for better quality assurance in the segmentation process of converting 2D-CT images to 3D-models.[31] Mathematical modeling and machine learning can also be applied to the VSP process to reduce dependency on the surgeon's and clinical engineer's abilities to select the best reconstruction solution. The surgeon can determine the two mandibular osteotomy sites, export the model into custom VSP software, and the optimization algorithm can determine the best reconstruction, with constraints applied such as minimal fibula segment length or maximal number of fibula segments.[26] Additionally, incorporating further imaging into the VSP process can enhance management of soft tissue and vasculature. For example, vessel mapping with angiographic CT or eco-color doppler can identify perforators relative to planned fibula osteotomies.[28] VSP can also integrate multimodality imaging including MRI and CT to better visualize bone marrow involvement with ORN and cancer as well as constraints relative to adjacent important soft tissue anatomy impacting the design of mandibular cutting guides.[31] VSP can incorporate dental implant placement at the time of mandibular reconstruction.[10] 3D-printed mandibular reconstruction plates are available and preferred over pre-bent plates because they yield more accurate results and are less prone to fracture.[19,38] Real time navigation and augmented reality can be employed, reducing the extent of soft tissue dissection, accommodating last minute changes while maintaining accuracy, and obviating the need for osteotomy guides.[39] Finally, in-house VSP with an employed engineer, a powerful workstation, an annually paid software license or in-house VSP software program, and in-house 3D-printing capacity can enhance control, access and autonomy during the planning, printing and accuracy assessment processes and potentially reduce costs.[26,32]

The retrospective nature of this study as well as the heterogeneity of the cohort, represent limitations. Ideally the CT utilized for post-operative accuracy analysis would have been ≤1.25 mm,[25] and obtained within 6 weeks of surgery and prior to any adjuvant radiation therapy,[25] and these parameters were not met in some cases. For optimal surgical planning, all patients would have had patient-specific preoperative CT of donor-bone (rather than generic or stock bone images) and patients would have had 3D custom milled plates made to exactly fit the form of their planned reconstruction. Had these measures been followed, our accuracy assessment might have more precisely reflected our results, and our outcomes might have been more accurate.

5 | CONCLUSION

This large cohort study found highly accurate results utilizing VSP/3Dprinted-guide/plate for osseous-free-flap reconstruction of mandibular defects. Not surprisingly, increased number of donor-bone segments and increased donor-bone length were associated with decreased accuracy. To help unify reporting and techniques among studies, we suggest using the Brown mandibular defect classification system and determining accuracy with 3D-model-overaly with the condyle as an anchor, comparing planned reconstruction to actual reconstruction, in four cephalometric measurements (IC, IG, AP, GA). This large case series, with high level of accuracy, further solidifies VSP/3Dprinted-guide/plate as an important tool for mandibular reconstruction.

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CONFLICT OF INTEREST

The authors and institution have no other funding support and no conflict of interests to declare.

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