FUNCTIONAL EVALUATION OF COMPUTER-ASSISTED MANDIBULAR RECONSTRUCTION WITH ILIAC CREST BONE GRAFT

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ABSTRACT

OBJECTIVE: The purpose of this study was to to assess the influence of computer-assisted mandibular reconstruction with iliac crest bone graft regarding the functional and morphological outcomes compared to the virtually performed surgery. Furthermore, the reliability of the measured values was evaluated.

MATERIALS AND METHODS: The study is a prospective case series for computer-assisted mandibular reconstruction patients with iliac crest graft. Primary outcome variable was the functional and morphological outcome variables when correlated to the virtual preoperative values. The secondary outcome was deciding the reliability of the utilized evaluation methodology. All recorded data were documented, tabulated, computed, and analyzed using inter-class coefficient (ICC) test . Statistical significance was set at the 5% level.

RESULTS: Nine consecutive patients were enrolled in this study. A highly statistically significant degree of agreement between the preoperative and postoperative measurements was recorded regarding all of the angular and linear parameters ($P<0.001$). Furthermore, an extreme degree of reliability was reported when the evaluation methodology was scrutinized. (ICC=0.9).

CONCLUSION: Computer-assisted reconstruction showed accurate postoperative condylar position and morphological orthognathic measurements in mandibular resection cases with iliac crest graft reconstruction. Furthermore, the study showed the reliability of the chosen methodology to evaluate the computer-assisted reconstruction procedure.

KEYWORDS: mandibular reconstruction, computer-assisted surgery, iliac crest bone.

RUNNING TITLE: Functional evaluation of computer-assisted mandibular reconstruction.

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INTRODUCTION

A drastic morphological and functional morbidity is expected with segmental mandibular resection surgeries with profoundly challenging reconstructive goals that requires an utmost degree of surgical fidelity. The predominant intention of mandibular reconstructive surgery is to create a functional orthognathic result with a centric condyle position, along with morphological and symmetrical form restoration of the lower third of the face (1,2).

Since its inception in the early 2000 by Hirsh, the concept of computer-Assisted Surgery (CAS) had a drastic impact on the mandibular reconstructive field (3). CAS edges the conventional free-hand technique in a plethora of aspects, offering a more effective and predictable reconstruction outcomes. Virtual Surgical Planning (VSP) provides the surgeon with a digitalized platform on which he can predict, anticipate, and prevent surgical complications (4-7).

Rodby et al defined CAS in reconstructive surgery as a four phased operation in a chronological order. The CAS processes starts with a virtual surgical planning phase, followed by a Three-Dimensional (3D) modeling phase, a surgical phase, and finally a postoperative evaluation phase (8). Despite being an integral part, postoperative evaluation analysis is usually overlooked (9,10). In a systematic review about the accuracy of CAS in mandibular reconstruction, van Baar et al concluded that there is a lack of homogeneity in the evaluation methodology that prohibited a meta-analysis calculation (11).

Vascularized fibular osteo-myo-cutaneous free flaps is the workhorse preference in mandibular reconstruction. Yet it is presented with several considerable shortcomings that would not guarantee optimal results in every situation. Microsurgeries and vascularized free transfer places a heavy burden on hospital resources and a greater financial load on the patient along with donor site morbidity, donor bone adequacy, and long operation period (12).

Non-Vascularized Bone Grafts (NVBGs) are an alternative modality for the reconstruction of medium-sized mandibular defects, notably for lateral mandibular defects (12-14). The leading choice for NVBGs in mandibular reconstruction is the Anterior Iliac Crest Graft (AICG), which brings forth a dependable and easily accessible harvesting site with an an adequate osseous bulk and contour for three-dimensional (3D) defect reconstruction (15,16). Bradley et al disclosed a 83% success rate when a NVBGs is implemented in medium sized mandibular defects, with linear dimension less than 7 cm (17). Although the indexed literature contains a plethora of computer-assisted mandibular reconstruction reports, the postoperative evaluation of CAS in mandibular reconstruction with iliac graft is poorly reported (5,9,11,15).

The aim of this study was to assess the influence of computer-assisted mandibular resection and iliac crest bone graft reconstruction regarding the functional and morphological outcomes compared to the virtually performed surgery. Furthermore, the reliability of the measured values was evaluated.

MATERIALS AND METHOD

Study Design

Local Research Ethics Committee approval was granted before the commencement of the study (IRB NO: 00010556-IORG: 0008839). And following the Helsinki Declaration guidelines, all patients signed an informed consent before the enrollment in this study.

A prospective case series study design was opted for to point out the importance of computer-assisted mandibular reconstruction in achieving a functionally and morphologically accepted reconstruction sequalae. Sample size calculation was performed assuming an estimated error of 5% and a study power of 80% using a one-sample t-test comparing the mean to a null value = zero (Gpower 3.0.10). A total of 9 patients was calculated.

Recruitment was performed from those admitted to the Outpatient Clinic of Alexandria University Teaching Hospital. All participants were eligible for mandibular segmental resection and reconstruction with non-vascularized anterior iliac crest bone graft. Patients with resection margin that involved the condyle were excluded, along with medically compromised patients, and those with previous history of operations or injuries in the groin and iliac region.

Preoperative Virtual Surgical Planning

A standard virtual planning protocol was appointed for all of the enlisted cases. A preoperative Computed Tomography (CT) scan for the maxillofacial and the pelvic region was obtained, and their Digital Imaging and Communications in Medicine (DICOM) data were fed into the planning software (Materialise innovation suite, Leuven, Belgium). High quality 3D- bone model visualization was obtained using thresholding, segmentation, and artifacts elimination. Virtual resection of the afflicted mandible was carried out with respect to the chosen safety margin to create a virtual proximal and distal osteotomy lines.

The created iliac and mandible bone models are imported to a 3D-planning software (3Matic; Materialise), and a Mandible Resection-Osteotomy Guide was along with a Reconstruction-Fixation Guide sharing the exact screws boreholes in both Guides. The Reconstruction-Fixation Guide is fabricated to maintain the 3D spatial relation between the proximal and distal segments after lesion resection and transfer this relation into the operation room.

The patients mid-sagittal plan was used to act as a reference plan to the mirroring tool to create a Neo-Mandible Model. This neo-model was used to create the Harvesting Iliac Osteotomy Guide, where areas with best fit to the mandibular defect that match the curve of the mandible is outlined. Union of the selected iliac contour along with the mirrored mandible was carried out to design the Virtually Reconstructed Preoperative Mandible (VPM).

Rapid prototyping of the various up-stated templets was performed using Fused Deposition Modelling (FDM) printing 3D printing technology. Pre-adaptation of the reconstruction plate was performed on the VPM, ensuring at least three screw holes in each bone stump. The printed guides were sterilized, following the Canter for Disease Control (CDC) guidelines.

Surgical procedures

A two-team approach was utilized in all the enrolled patients, where the first team prepared the mandible recipient site and the second one harvests the iliac crest bone graft. Following the exposure of the mandible via a second neck crease incision, the Mandible Resection-Osteotomy Guide is fitted and fixed via 2.0 mini-screws, and resection of the affected part of the mandible is performed using proximal and distal osteotomies. This was followed by replacing the resection guide with the Reconstruction-Fixation Template, using the same screw boreholes created for fixation of the resection template. The fixation template enabled the placement of the Pre-Adapted Reconstruction Plate by maintaining the spatial relation between the bony stumps.

Concurrently, the Harvesting Iliac Osteotomy

Guide was fitted to the anatomy of the iliac tubercle, and was used to harvest the graft which is then fixed with the reconstruction plate in the pre-planned position.

Creation of postoperative models

For each participant, an immediate postoperative CT scan was obtained within seven days of the operation. Segmentation of the postoperative DICOM data was performed and an Actual Postoperative Mandible (APM) model was created for high quality 3D-visualization of the postoperatively reconstructed mandible (18,19) (Figure 1).

Functional and morphological outcomes of Computer-assisted reconstruction.

For each participant, preoperative VPM model and postoperative APM model were imported to a 3D-analysis software (GOM Inspect Pro 2019, GmbH, Braunschweig, Germany). Several points were outline in both models to act as measuring landmarks. These points are pointed out in Figure 2.

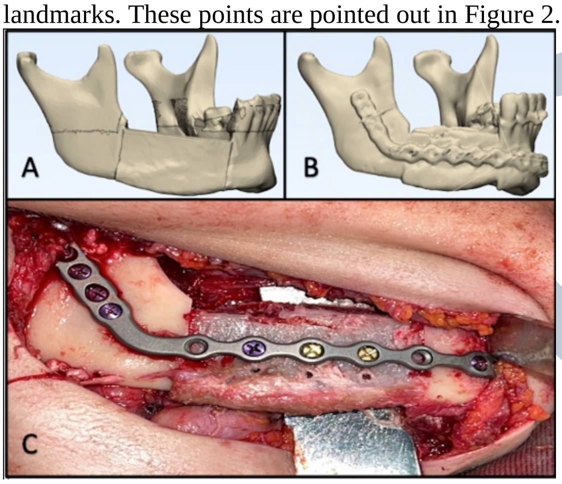


Figure 1. High quality Three-dimensional visualization of bone models. A, preoperative virtual bone model. B, Postoperative actual bone model. C, clinical picture showing iliac crest in place after reconstruction of the segmental mandibular defect.

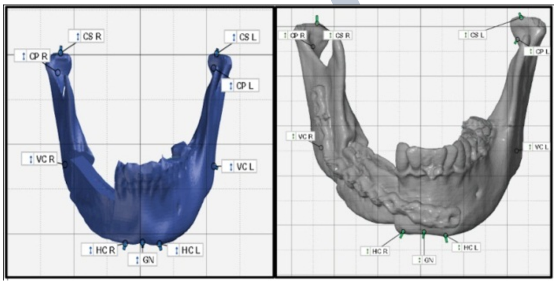


Figure 2. Preoperative and postoperative landmark placement.

- Condylar Superior (CS): The most superior and medial point of the condyle.
- Condylar Posterior (CP): The most posterior point of the condyle.
- Vertical Corner (VC): The most superior point of the angle of the mandible.
- Horizontal Corner (HC): The canine eminence line.
- Gnathion (GN): The lowest point of the midline of the lower jaw.
- Mid-sagittal Plan: Plan passing the nasion, incisive foramen, and basion.

Several functional and morphological parameters were measured. These are: (18,19):

- Axial mandibular angle (AMA): The angle between the VC-HC line and the patient's mid-sagittal plan.
- Condylar mandibular angle (CMA): The angle between the CS-VC line and the patient's mid-sagittal plan.
- Sagittal Mandibular Angle (SMA): The angle between the CP-VC and HC-VC lines (Figure 3).
- Inter-Condylar Distance (ICD): The linear distance measured from CS to contralateral CS.
- Inter-Gonial Distance (IGD): The linear distance measured from VC to contralateral VC.
- Antero-Posterior Distance (APA): The linear distance measured from GN to its projection on the ICD line (Figure 4).

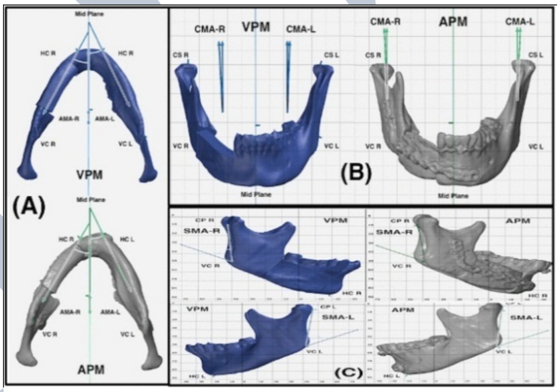


Figure 3. Preoperative and postoperative Angular mandibular measurements. A, Axial mandibular angles. B, Coronal mandibular angles. C, Sagittal mandibular angles.

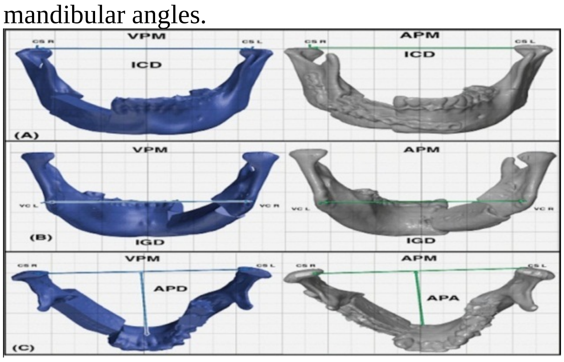
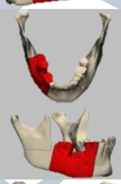


Figure 4. Preoperative and postoperative linear mandibular measurements. A, Inter-Condylar distance. B, Inter-Gonial distance. C, Antero-Posterior distance.

Statistical Analysis

Data were analyzed using IBM SPSS for windows version 23.0. (IBM Corp, NY, USA). The APM

Table 1: Patients Demographic Data

N	Age / Sex	Resectio Etiology	Defect classification (Brown)	Reconstr ction	Virtual Resection
1	35/ M	Amelobl stoma	II	Primary	
2	47/F	Amelobl stoma	I	Primary	
3	28/F	Amelobl stoma	II	Primary	
4	51/ M	Amelobl stic Carcinom a	II	Primary	
5	54/F	Fibro-myxoma	II	Primary	
6	28/F	Acantho matous Amelobl stoma	I	Primar	
7	38/F	Fibro-myxoma	I	Primary	
8	17/F	Fracture non-union	II	Seconda	
9	39/ M	Amelobl stoma	II	Primary	

n, Number; yr, Year; M, Male; F, Female; M:F, Male: Female Ratio

measurements were correlated to the VPM, and the degree of agreement between the preoperative and the postoperative measurements was investigated using a two-tailed Intra Class Correlation Coefficient (ICC) test. A key to apprehend the outcome values of the ICC is presented; <0.5 Poor agreement, 0.5 to <0.75 Moderate agreement, 0.75 to <0.9 Good agreement, 0.9 - 1.0 Excellent agreement (20). Significance level was confirmed at P value of 0.05.

The reliability of the measured data was assessed by Inter-observer reliability test, as for each patient records their data were evaluated by two separate investigators (Y.E, A.E). Inter-observer reliability was inspected by a two-way mixed ICC test to determine the degree of conformity between the iterations of two separate auditor.

A key to apprehend the outcome values of the ICC is presented; <0.5 Poor agreement, 0.5 to <0.75 Moderate agreement, 0.75 to <0.9 Good agreement, 0.9 - 1.0 Excellent agreement [20]. Significance level was confirmed at P value of 0.05.

RESULTS

The characteristics, demographic data, and diagnoses of the enrolled nine patients is presented in Table 1. The study reported a 0.5:1 male to female ratio, with a 37.4 ±12.01 years reported mean age.

Agreement between preoperative and postoperative computations was analysed using ICC. All of the studied angular and linear measurements revealed an excellent degree of agreement when the preoperative and postoperative measurements were correlated (ICC value 0.9 to 1) part from the right and left CMA, which revealed a good degree of agreement (0.75 to <0.9). A statistically significant correspondence was obtained between the virtually planned values and the actual measurements for both the linear and angular measurements (P ranges from 0.012* to <0.0001*) (Table 2).

Two separate investigators performed the data collection and Inter-observer reliability test was used to assess the reliability of the measured data. Apart from the CMA and ICD, all of the measured variables should an excellent degree of agreement between the measurements of both investigators (ICC=0.9-1.0). The CMA and ICD readings computed a good degree of agreement (ICC = 0.75 to <0.9) (Table 3).

Table 3: Intra Examiner Reliability of the measurements made by the main observer and the other observer.

		ICC	P
AMA	**R**	0.972	**<0.0001***
	L	0.947	**<0.0001***
CMA	**R**	0.841	**0.012***
	L	0.888	**0.004***
SMA	**R**	0.949	**<0.0001***
	L	0.976	**<0.0001***
ICD		0.785	**0.027***
IGD		0.954	**<0.0001***
APD		0.948	**<0.0001***

Actual Postoperative Model; VPM, Virtual Preoperative Model; AMA, Axial Mandibular Angle; CMA, Coronal Mandibular Angle; SMA, Sagittal Mandibular Angle; R, Right Side; L, Left Side; ICC, Interclass Correlation Coefficient.
ICC Outcome Values: <0.5 Poor agreement, 0.5 to <0.75 Moderate agreement, 0.75 to <0.9 Good agreement, 0.9 - 1.0 Excellent agreement.
*Statistically significant difference at p value≤0.05.

DISCUSSION

Several reports regarding the use of computer assisted surgeries in mandibular reconstruction with fibular flaps are available in the indexed literature, yet the literature come short in the number of manuscripts that evaluates the accuracy of mandibular reconstruction with iliac crest bone graft (5,9,11). Various scenarios can be virtually encountered and avoided with the aid of computer-assisted mandibular reconstruction surgeries. This led to an increased predictability of the operation, along with evading possible complications (8). This study evaluated the integration of computer-assisted surgeries and rapid prototyping technologies in mandibular reconstruction using iliac crest bone graft.

The abrupt angulations in the innate mandibular bone anatomy makes its reconstruction a challenging task to restore this angular configuration (21). Hence, the use of mandibular angles as a predictive variable for the morphological outcome of the reconstruction is a common notion (21,22). In a systematic review about the accuracy of CAS in mandibular reconstruction, angular deviation was considered in 17 cases, and the range of reported postoperative deviation results was 0.9° and 17.5° (11). Furthermore, and to our knowledge, the implantation of angular deviation assessment to determine the accuracy of computer aided iliac crest bone graft mandibular reconstruction has not

Table 2: Analysis of the degree of agreement between the APM and the VPM Angular measurements and Linear measurements.

		ICC	P
AMA	**R**	0.863	**<0.0001***
	L	0.978	**<0.0001***
CMA	**R**	0.841	**0.012***
	L	0.894	**<0.0001***
SMA	**R**	0.984	**<0.0001***
	L	0.987	**<0.0001***
ICD		0.987	**<0.0001***
IGD		0.979	**<0.0001***
APD		0.988	**<0.0001***

Actual Postoperative Model; VPM, Virtual Preoperative Model; AMA, Axial Mandibular Angle; CMA, Coronal Mandibular Angle; SMA, Sagittal Mandibular Angle; R, Right Side; L, Left Side; ICC, Interclass Correlation Coefficient.
ICC Outcome Values: <0.5 Poor agreement, 0.5 to <0.75 Moderate agreement, 0.75 to <0.9 Good agreement, 0.9 - 1.0 Excellent agreement.
*Statistically significant difference at p value≤0.05.

been described previously.

De Maesschalck et al introduced the concept of axial, coronal, and sagittal mandibular angles for the assessment of hard tissue morphological outcomes after mandibular reconstruction surgery (22). Their report calculated the mean angular deviation values of 1.0°, 1.8°, and 4.2° for each mandibular angle. They deemed their outcome by CAS as morphometric accurate (22). Angular deviation was also utilized by Weitz et al, where a range of 0°–18° degree of deviation was calculated (23). Mandibular angular measurements provide a numerical assessment tool to quantify the overall morphology of the lower third of the face giving a valid indication regarding the quality of the computer-assisted reconstruction processes in maintain the normal preoperative morphological appearance.

The use of transverse, ICD and IGD, and sagittal dimensions, APD as linear measurements to outline the mandibular morphological and functional outcome is another trivial evaluation methodology (4,10,21-25). Foley et al studied the linear deviation of CAS mandibular reconstruction utilizing iliac crest graft (15,26-28). Analysis of linear deviations provides a simple mean to correlate surgical accuracy to functional outcome in ICD, and morphological outcome, in IGD and APD.

The mandibular reconstruction procedure owns several components that act as confounding factors to optimally statistically correlate surgical bony reconstruction results with optimal functional outcomes (11,29). All of the indexed computer-assisted surgeries evaluation studies are deprived of a statistical analysis tool to their reported results. In the majority of the studies a mere statement of considering their reported outcome as accurate is a common practice (22,23,30). In this study, the degree of agreement between the virtual preoperative and the actual postoperative measurements was utilized as a statistical analysis tool to outline the surgical outcomes of the computer-assisted operation. Testing the degree of data accordance is a more valid and comprehensible was than testing the degree of error between the data (20). This study utilized ICC test to show the degree of data agreement, and in all of the measured variables, a statistically significant degree of agreement was obtained.

Inter-examiner reliability is the degree of agreement among independent observers who assess the same variables. It is important to assess data reliability to point out the validity in the chosen evaluation methodology (20). This study disclosed a statistically significant inter-observer reliability (ICC=0.9-1.0). The reported high level of reliability outlines the validity of the reported methodology in evaluating the functional and morphological behaviour of computer-assisted mandibular reconstruction.

The literature is inconsistent in the computer-assisted surgical protocol, which may point out the sacristy of reliability testing in mandibular reconstruction studies (31-33). Ritschl et al reported a very good intra- and interobserver reliabilities for transverse linear measurements in mandibular reconstructions with fibular flap (33). Despite yielding similar outcome in this study (31-33), it cannot be corelated to our results owing to the diverse methodology. However, this may validate the use of the STL model comparison and deviation as a reliable and reproducible accuracy assessment technique.

Mandibular joint functional abnormalities can be linked to several factors in a mandibular reconstruction surgery, such as, condylar disk displacement, increased condylar space, wrong postoperative condylar position, and failure to regain normal occlusion (26). Dysfunction in the temporomandibular joint function can drastically affects the patient’s quality of life. This may be averted by avoiding diversification in the condylar head position and malocclusion, which are commonly a result of alteration in the bony stumps position following mandibular resection (26).

In this study an excellent degree of agreement when the virtual and actual postoperative ICD were correlated. (ICC = 0.987). This agreement was statistically significant agreement. This may be conceived as a negligible difference in the postoperative condylar position with an inconsequential effect on the normal work of the temporomandibular joint and lower the probability of joint dysfunction.

Computer-assisted surgeries and preoperative virtual planning gives the surgeon an added leverage of preoperative complications anticipation, in conjugation to the pre-adaptation of the reconstruction plate (3,11,29). The handful of advantages of the computer-assisted mandibular surgeries are well-known, and their added influence almost always outweigh their drawbacks. Yet, there is a common consensus regarding the lack of a uniform standard for computer-assisted mandibular reconstruction surgeries, as it is engineer/surgeon experience-based (3,11,29).

This study further added confirmation regarding the accuracy of CAS in mandibular reconstruction with iliac crest bone graft, which falls in line with the literature consensus about the surgical outcomes. A novel statistical analysis concerned with the degree of agreement of the virtual and actual postoperative linear and angular measurements is proposed in this study which revealed an excellent degree of accordance between these measurements, indicating an excellent bony accuracy of the CAS and surgical procedure. Furthermore, the study pointed out the high degree of reliability of the obtained results, along with the ease of application of the chosen methodology. The use of a slandered statistical evaluation method may be a first step in the attempt to standardize the evaluation criteria and obtaining a tolerable value for the acceptable postoperative mandibular reconstruction results. The use of a common postoperative evaluation methodology along with a standard statistical analysis tool in future studies is needed in order to perform a metanalysis study regarding the computer-assisted mandibular rehabilitation with various reconstructive options.

CONCLUSION

Computer-assisted reconstruction showed accurate postoperative condylar position and morphological orthognathic measurements in mandibular resection cases with iliac crest graft reconstruction. These favorable functional and morphological outcomes were further assessed as a reliable outcome as the results showed an excellent degree of reliability.

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Conflict Of Interest

The authors declare that they have no conflicts of interest. The authors declare that they received no funding to perform this study.

REFERENCES

1. Bak M, Jacobson AS, Buchbinder D, Urken ML. Contemporary reconstruction of the mandible. Oral Oncol. 2010;46:71–6. DOI: 10.1016/j.oraloncology.2009.11.006.
2. Brown JS, Barry C, Ho M, Shaw R. A new classification for mandibular defects after oncological resection. Lancet Oncol. 2016;17:e23–30. DOI: 10.1016/S1470-2045(15)00310-1.
3. Hirsch DL, Garfein ES, Christensen AM, Weimer KA, Saddeh PB, Levine JP. Use of computer-aided design and computer-aided manufacturing to produce orthognathically ideal surgical outcomes: a paradigm shift in head and neck reconstruction. J Oral Maxillofac Surg 2009;67:2115–22. DOI: 10.1016/j.joms.2009.02.007.
4. Zhang L, Liu Z, Li B, Yu H, Shen SG, Wang X. Evaluation of computer-assisted mandibular reconstruction with vascularized fibular flap compared to conventional surgery. Oral Surg Oral Med Oral Pathol Oral Radiol. 2015;121:139–48. DOI: 10.1016/j.oooo.2015.10.005.
5. Shu, Dl., Liu, Xz., Guo, B. et al. Accuracy of using computer-aided rapid prototyping templates for mandible reconstruction with an iliac crest graft. World J Surg Onc. 2014;12;190. DOI: https://doi.org/10.1186/1477-7819-12-190.
6. Ciocca L, Marchetti C, Mazzoni S, Baldissara P, Gatto MRA, Cipriani R, Scotti R, Tarsitano A. Accuracy of fibular sectioning and insertion into a rapid-prototyped bone plate, for mandibular reconstruction using CAD-CAM technology. J Craniomaxillofac Surg. 2015; 43: 28-33. DOI: https://doi.org/10.1016/j.jcms.2014.10.005 .
7. Hanasono MM, Skoracki RJ. Computer-assisted design and rapid prototype modeling in microvascular mandible reconstruction. Laryngoscope. 2013;123:597-604. DOI: 10.1002/lary.23717.
8. Rodby, K. A. et al. Advances in oncologic head and neck reconstruction: systematic review and future considerations of virtual surgical planning and computer aided design/computer aided modeling. J Plast Reconstr Aesthet Surg. 2014;67:1171-85. DOI: 10.1016/j.bjps.2014.04.038.
9. Juergens P, Klug C, Krol Z, et al: Navigation-guided harvesting of autologous iliac crest graft for mandibular reconstruction. J Oral Maxillofac Surg. 2011;69: 2915. DOI: 10.1016/j.joms.2010.12.045.
10. Succo G, Berrone M, Battiston B, Tos P, Goia F, Appendino P, et al. Step-by-step surgical technique for mandibular reconstruction with fibular free flap: application of digital technology in virtual surgical planning. Eur Arch Otorhinolaryngol. 2015;272:1491–501. DOI: 10.1007/s00405-014-3078-3.
11. van Baar G, Forouzanfar T, Liberton N, Winters H, Leusink F. Accuracy of computer-assisted surgery in mandibular reconstruction: A systematic review. Oral Oncol. 2018;84:52-60. DOI: 10.1016/j.oraloncology.2018.07.004.
12. van Gemert JT, van Es RJ, Van Cann EM, Koole R. Nonvascularized bone grafts for segmental reconstruction of the mandible--a reappraisal. J Oral Maxillofac Surg. 2009; 67:1446-52. DOI: 10.1016/j.joms.2008.12.052.
13. Habib, A. and Hassan, S. The feasibility of rib grafts in long span mandibular defects reconstruction: A long term follow up. J Craniomaxillofac Surg. 2019;4715-22. DOI: 10.1016/j.jcms.2018.11.002.
14. Ren, Z., Fan, T., Zhang, S. and Wu, H.,. Nonvascularized Iliac Bone Reconstruction for the Mandible Without Maxillofacial Skin Scarring. J Oral Maxillofac Surg. 2020; 78: 288-94. DOI: 10.1016/j.joms.2019.09.012.
15. Foley B, Thayer W, Honeybrook A, McKenna S, Press S. Mandibular Reconstruction Using Computer-Aided Design and Computer-Aided Manufacturing: An Analysis of Surgical Results. J Oral Maxillofac Surg. 2013;71:e111-9. DOI: 10.1016/j.joms.2012.08.022.
16. Boehm KS, Al-Taha M, Morzycki A, Samargandi OA, Al-Youha S, LeBlanc MR. Donor Site Morbidities of Iliac Crest Bone Graft in Craniofacial Surgery: A Systematic Review. Ann Plast Surg. 2019;83:352-8. DOI: 10.1097/SAP.0000000000001682.
17. Bradley AJ, David HS, Warren RM. Vascularized versus Nonvascularized Bone Grafts: What Is the Evidence?. Clin Orthop Relat Res. 2016;474:1319-27. DOI: 10.1007/s11999-016-4769-4.
18. van Baar G, Liberton N, Forouzanfar T, Winters H, Leusink F. Accuracy of computer-assisted surgery in mandibular reconstruction: A postoperative evaluation guideline. Oral Oncol. 2019;88:1-8. DOI: 10.1016/j.oraloncology.2018.11.013.
19. van Baar, G. J. C., Liberton, N. P. T. J., Winters, H. A. H., Leeuwrik, L., Forouzanfar, T., Leusink, F. K. J. A Postoperative Evaluation Guideline for Computer-Assisted Reconstruction of the Mandible. J. Vis. Exp. 2020;155: e60363. DOI:10.3791/60363.

20. Han X. On Statistical Measures for Data Quality Evaluation. J Geogr Inf Syst. 2020;12: 178-87. DOI: https://doi.org/10.4236/jgis.2020.123011.
21. Tarsitano A, Ciocca L, Scotti R, Marchetti C. Morphological results of customized microvascular mandibular reconstruction: A comparative study. J Craniomaxillofac Surg. 2016;44:697-702. DOI: 10.1016/j.jcms.2016.03.007.
22. De Maesschalck T, Courvoisier D, Scolozzi P. Computer-assisted versus traditional freehand technique in fibular free flap mandibular reconstruction: a morphological comparative study. Eur Arch Otorhinolaryngol. 2016;274:517-26. DOI: 10.1007/s00405-016-4246-4.
23. Weitz J, Bauer FJ, Hapfelmeier A, Rohleder NH, Wolff KD, Kesting MR. Accuracy of mandibular reconstruction by three-dimensional guided vascularized fibular free flap after segmental mandibulectomy. Br J Oral Maxillofac Surg. 2016;54:506-10. DOI:10.1016/j.bjoms.2016.01.029.
24. van Baar GJC, Leeuwrik L, Lodders JN, Liberton NPTJ, Karagozoglu KH, Forouzanfar T and Leusink FKJ. A Novel Treatment Concept for Advanced Stage Mandibular Osteoradionecrosis Combining Isodose Curve Visualization and Nerve Preservation: A Prospective Pilot Study. Front Oncol. 2021;11:630123. DOI: 10.3389/fonc.2021.630123.
25. Metzler P, Geiger EJ, Alcon A, Ma X, Steinbacher DM (2014) Three-dimensional virtual surgery accuracy for free fibula mandibular reconstruction: planned versus actual results. J Oral Maxillofac Surg 72:2601–2612
26. Ayoub, N., Ghassemi, A, Rana, M, Rana M, Gerressen M, Riediger D, Hölzle F, et al. Evaluation of computer-assisted mandibular reconstruction with vascularized iliac crest bone graft compared to conventional surgery: a randomized prospective clinical trial. Trials. 2014;9;15:114. DOI: https://doi.org/10.1186/1745-6215-15-114.
27. Zheng L, Lv X, Zhang J, Liu S, Zhang J, Zhang Y. Translating Computer-Aided Design and Surgical Planning Into Successful Mandibular Reconstruction Using a Vascularized Iliac-Crest Flap. J Oral Maxillofac Surg. 2018;76:886-93. DOI: 10.1016/j.joms.2017.10.026.
28. Li Y, Shao Z, Zhu Y, Liu B, Wu T. Virtual Surgical Planning for Successful Second-Stage Mandibular Defect Reconstruction Using Vascularized Iliac Crest Bone Flap: A Valid and Reliable Method. Ann Plast Surg. 2020;84:183-7. DOI: 10.1097/SAP.0000000000002102.
29. Barr ML, Haveles CS, Rezzadeh KS, Nolan IT, Castro R, Lee JC, et al. Virtual Surgical Planning for Mandibular Reconstruction With the Fibula Free Flap: A Systematic Review and Meta-Analysis. Ann Plast Surg. 2020;84:1. DOI: 10.1097/SAP.0000000000002006.
30. Roser SM, Ramachandra S, Blair H, Grist W, Carlson GW, Christensen AM, et al. The accuracy of virtual surgical planning in free fibula mandibular reconstruction: comparison of planned and final results. J Oral Maxillofac Surg. 2010;68:2824–32. DOI: 10.1016/j.joms.2010.06.177.
31. Hanken H, Schablowsky C, Smeets R, Heiland M, Sehner S, Riecke B, et al. Virtual planning of complex head and neck reconstruction results in satisfactory match between real outcomes and virtual models. Clin Oral Investig 2015;19:647–56. DOI: 10.1007/s00784-014-1291-5.
32. Weijs W, Coppen C, Schreurs R, Vreeken R, Verhulst A, Merkx M et al. Accuracy of virtually 3D planned resection templates in mandibular reconstruction. J Craniomaxillofac Surg. 2016;44:1828-1832. DOI: 10.1016/j.jcms.2016.08.024.
33. Ritschl LM, Kilbertus P, Grill FD, Schwarz M, Weitz J, Nieberler M, Wolff K-D and Fichter AM. In-House, Open-Source 3D- Software-Based, CAD/CAM-Planned Mandibular Reconstructions in 20 Consecutive Free Fibula Flap Cases: An Explorative Cross-Sectional Study with Three-Dimensional Performance Analysis. Front Oncol. 2021;11:731336. DOI: 10.3389/fonc.2021.731336.