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 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.

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 digitized 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 sequelae. 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 on the VPM, ensuring at least three screw boreholes created for fixation of the resection area with best fit to the mandibular defect. 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 templates 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 Center 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.

- **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).

**Statistical Analysis**

Data were analyzed using IBM SPSS for windows version 23.0. (IBM Corp, NY, USA). The APM
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 (P ranges from 0.012* to <0.0001*) (Table 2).
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Table 3: Intra Examiner Reliability of the measurements made by the main observer and the other observer.

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
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<tbody>
<tr>
<td>AMA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
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<td>&lt;0.0001*</td>
</tr>
<tr>
<td>L</td>
<td>0.947</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>CMA</td>
<td></td>
<td></td>
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<tr>
<td>R</td>
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<td>0.012*</td>
</tr>
<tr>
<td>L</td>
<td>0.888</td>
<td>0.004*</td>
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<tr>
<td>SMA</td>
<td></td>
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<tr>
<td>R</td>
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<td>&lt;0.0001*</td>
</tr>
<tr>
<td>L</td>
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<tr>
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<td>APD</td>
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<td>&lt;0.0001*</td>
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Table 2: Analysis of the degree of agreement between the APM and the VPM Angular measurements and Linear measurements.

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<th>ICC</th>
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<td>M</td>
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<tr>
<td>CMA</td>
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<tr>
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<tr>
<td>M</td>
<td>0.894</td>
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<tr>
<td>M</td>
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<td>&lt;0.0001*</td>
</tr>
<tr>
<td>ICD</td>
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<td>&lt;0.0001*</td>
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<tr>
<td>IGD</td>
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<td>&lt;0.0001*</td>
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<tr>
<td>APD</td>
<td>0.988</td>
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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 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 correlated 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.

**Acknowledgements**

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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