Digital Surgical Planning for Mandibular Reconstruction With Free Fibula Flap: Is the Accuracy Affected by the Number of Compromised Mandibular Segments?

Oncologic head and neck surgery group Oncologic head and neck surgery group
   Instituto de Cancerología IDC Las Américas
TECHFIT Digital Surgery TECHFIT Digital Surgery
   Industrias Médicas Sampedro   https://orcid.org/0000-0002-5392-1845
Aura Cardona (aura.cardona@imsampedro.com)
   Industrias Médicas Sampedro. Medellín, Colombia

Research

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Abstract

**Background:** Reconstructive mandibular surgery using free fibular flap in patients with defects due to oncologic resections aims to restore the lost functionality and appearance. Digital surgical planning (DSP) aids in designing the procedure through three-dimensional (3D) visualization of the anatomical defect, flap positioning, and contour restoration. Some studies have explored the DSP for assistance with mandibular reconstructions; however, most are limited in sample size and geographic region where these resources are available. Here we present a step-by-step DSP and the results obtained in a cohort of patients analyzed according to the number of compromised mandibular segments.

**Methods:** We retrospectively analyzed 90 procedures in which DSP was applied, from patients who underwent oncologic mandibulectomy and reconstruction using a free fibula flap from 2012 to 2019. Customized cutting guides and implants were used in all patients. Clinical data was obtained from medical records and information concerning the DSP from company archives. Ethics committee approval was obtained.

**Results:** Patient’s median age was 60 years; 52% were women. The most common tumor was squamous cell carcinoma in 49.4%. The medians of the mandibular defect volume and the length of the whole fibula flap were 12.24 cm$^3$ and 9.24 cm. More than one mandibular segment was compromised in 44% of the patients. The median surgical and flap ischemia times were 380 and 76 minutes, respectively. In 95.5% cases, excellent bone apposition was achieved; four cases required minor intraoperative adjustments. Median follow-up was 14 months, and the complication rate was 18.9%. Satisfactory functional and aesthetic results were achieved in more than 60 and 70% of the cases. There were no differences in those outcomes according to the number of mandibular segments resected and reconstructed.

**Conclusion:** The digitally planned mandibular reconstructive procedures showed highly satisfactory results. The technology facilitated the completion of procedures without deviating from the surgical plan or requiring onsite adjustments. The latter indicated the high accuracy of the surgical plan. The customized cutting guides and plates optimized the surgical precision and times for a low complication rate and adequate overall results independently of the number of compromised mandibular segments and procedure's complexity.

**Background**

The head and neck neoplasms frequently invade mandibular bone structures requiring extensive resections with the consequent functional and aesthetical losses (1–3). The resulting deformities produce deleterious psychological, physical, functional, and nutritional effects (1–5). Reconstructive mandibular surgery offers patients the means to restore the anatomy, functionality, and, therefore, a better quality of life (1, 6, 7).

The microvascular free fibular flap (MFFF) is now considered the gold standard procedure for reconstructing the jaw, given its favorable bone characteristics and a reported high success rate (1, 4, 8–
Regularly, bone segments are cut and manipulated based on empirical measurements and fixed using reconstruction plates bent manually by the surgeon according to the jaw’s morphology (6, 7, 12, 13). This method has shown adequate results but requires great surgical expertise to minimize errors and can lead to an increased risk of flap ischemia in addition to prolonged surgical times (2, 6, 7, 10).

Digital Surgical Planning (DSP) is widely used for the presurgical design of such complex facial reconstructive surgery (4, 10, 14). The DSP provides the surgeon with an opportunity to design, analyze, and forecast surgical complications, avoiding improvisations during the procedure (4, 10, 14–16). Advances in computer-aided design (CAD) and computer-aided manufacturing (CAM) software have resulted in the ability to manipulate three-dimensional (3D) models of the facial skeleton to perform a virtual reconstruction of missing or abnormal parts (6, 7, 16, 17). The application of CAD/CAM techniques is also used to manufacture cutting guides based on preoperative imaging. The personalized guides eliminate the need for intraoperative measurements, making it possible to obtain more precise bone segments and better symmetry (6–8, 10, 16).

The existing publications reporting outcomes of MFFF for mandibular reconstruction in patients undergoing extensive surgical resections planned digitally using different technological solutions are limited in sample size, mostly constrained to clinical approaches. Additionally, those reports are generated from geographical regions where the CAD/CAM technology is readily available (1, 2, 10, 14–16, 22–24).

In this work, we aimed to assess the results obtained with a full DSP, including custom-made guides and implant design in a large cohort of patients who underwent mandibular reconstruction using MFFF secondary oncologic resections. The DSP and customized devices' accuracy was assessed through the intraoperative variables and results according to the number of compromised mandibular segments.

**Methods**

**Patients**

The ethics committee and institutional review board at Instituto de Cancerología IDC Las Americas approved the study (04-2019, March 27/2019); the Helsinki Declaration guidelines were followed. We performed a retrospective review of 90 consecutive patients who, from 2012 to 2019, underwent concomitant procedures of tumor resection and mandibular reconstructive surgery secondary to neoplasms. All the procedures were performed by either experienced head and neck, plastic, or oral and maxillofacial surgeons and were planned using DSP technology. Patients included in the study required the harvest of an MFFF to repair extensive mandibular defects. Details regarding demographic characteristics, operative notes, and patient follow-up data were compiled from the medical records.

**Step-by-step 3D DSP and customized guides and implants design**
1. The patient-fitted surgical planning began with high-resolution computed tomography (CT) scans of
the maxillofacial skeleton and the associated soft tissues. CT angiography (angiogram) of lower extremities was obtained to evaluate the donor site's bone and vessel quality.

2. All the DICOM (Digital Imaging and Communication in Medicine) files from the CT scans were imported into the Materialise Mimics® Innovation Suite (Leuven, Belgium). The 2D images were converted into virtual 3D models as Standard Tessellation Language (STL) files (Figure 1).

3. The models' images were oriented and centered before segmenting the mandibular structures from the rest of the skull (Figure 2). From there, the reconstructive team designed a digital simulation of the surgery, considering the required osteotomies for the complete tumor resection with free margins (Figure 3).

4. The resulting anatomical space was analyzed in detail to plan the next step; the fibula side (right or left) and the segment's position (more distal or more proximal) were decided in this step of the process (Figure 4).

5. The fibula was digitally placed on the anatomical defect to calculate the segment's length needed to repair it, and the osteotomies required to achieve the native mandibular contour (Figure 5).

6. Next, the guides are designed considering the extensión and direction of each bone's required cuts (Figure 6).

7. The 3D models of the patient's defect and fibula generated with the 3Matic® were then 3D printed.

8. Rapid prototypes of all the components of the cutting guides and implants were created in medical-grade ABS and used to carry out the operation on the previously printed models. The validation of the surgical solution assured that the implant geometry matched the patient's bone structure and that the correct occlusion could be achieved with the surgery.

9. The mechanical performance of the reconstruction plates was verified using finite element analysis. They were manufactured with commercially pure grade 4 titanium to ensure better osseointegration and the highest quality standards. The osteotomy guides for both mandible and fibula were also manufactured.

**Surgical procedure**

The procedure was performed with a two-team approach; one team was in charge of the ablative portion, while the second team harvested the fibula flap.

The mandibulectomy was performed according to the digital plan. For the MFFF harvest, the surgical team dissected the osteocutaneous fibula flap and separated it on the vascular pedicle. The cutting guides were placed and secured to the bone. The osteotomies were performed with an oscillating saw following the cutting guides and reproducing the DSP at the harvesting positions. The segments were fixated together with custom made pre-bent reconstruction plates. Finally, the vascular pedicle was detached, and the flap was transferred to the reconstruction area.
Completing the reconstruction was achieved by securing the graft's osseous component to the mandibular segments at its digitally pre-planned ideal position and finalizing the vascular anastomoses.

**Outcome measurements**

The outcome measurements included surgical and ischemia times, complications, and surgical plan deviations (onsite adjustments). Tumoral recurrence, aesthetic appearance, oral communication, masticatory function, and facial symmetry achievement were recorded during the last follow-up visit registered at each patient's clinical file as indicators of the DSP accuracy.

Aesthetical outcomes were assessed by the subjective evaluation of the surgeon through visual analog scale (VAS) and classified according to the score as excellent (9-10), fair (6-8), deficient (3-5), and poor (0-2).

Functional outcomes were evaluated through speech and mastication.

The speech was classified into three categories: clear communication, no clear communication, and impossible oral communication. The masticatory function was categorized according to the patient's diet into regular, soft, or nasogastric tube feeding.

**Analysis and statistics**

Descriptive statistical analyses were performed with the IBM SPSS Statistics 25 software (Chicago, IL). According to the dataset distribution, medians and the 95% confidence intervals (95%CI) were used to describe quantitative values. Absolute and relative frequencies were used to describe categoric variables. A p-value of less than 5% was considered significant for the stratified analysis.

**Results**

Ninety patients underwent mandibular surgical resection and reconstruction with DSP technology from 2012 to 2019. The study population included 43 males and 47 females, with a median age of 60 (range, 12–94 years). The most frequent histologically diagnosed tumor was squamous cell carcinoma in 49.4% of the patients. In 44.4% of the cases, the tumor involved more than one mandibular segment.

The median mandibular volume defect repaired during the reconstructive surgery was 12.24 cm$^3$ (range from 0.5 to 3.6 cm$^3$). The median length of the whole fibula flap used for the repair was 9.24 cm (range, 3.5–16.6 cm).

The total surgical time ranged from 300 to 670 minutes (median 380 minutes), and the flap ischemia time ranged from 45–130 minutes (median 76 minutes).

In 95.5% of the cases, the mandibular resections and osteotomies performed with custom-made cutting guides produced fibular segments with perfect fit and excellent apposition. In the operating room and
during the modeling, only four patients required onsite minor adjustment to the fibular bone segments and the holes' position to secure the implants.

The total complication rate was 18.9%: surgical wound infection in 11.1%, and osteosynthesis material (implant) rejection in 7.8%.

The median time of follow-up was 14 months (range, 4–92), during which six patients were lost (6.7%). Among the 84 remaining patients, 11.9% had documented tumor recurrence.

From a functional and aesthetical standpoint, 61.9% of the patients could tolerate a regular diet, 63.1% had clear oral communication, and 73.8% had an excellent appearance during the last follow-up. Facial symmetry was achieved by 91.6%.

A stratified analysis by the number of compromised mandibular segments is presented in Table 1. The analysis showed the same trend of results independently of the procedure's complexity with no significant differences amongst the three groups; even in those with more than two mandibular segments involved, the planned procedures were accurate.
Table 1
Basal clinical characteristics, surgical information, and postoperative results

<table>
<thead>
<tr>
<th>Number of compromised mandibular segments</th>
<th>One segment (50)</th>
<th>Two segments (26)</th>
<th>Three segments (14)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Male</td>
<td>23</td>
<td>12</td>
<td>8</td>
<td>0.747</td>
</tr>
<tr>
<td>• Female</td>
<td>27</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>*Age</td>
<td>65 (49–64)</td>
<td>59 (52–66)</td>
<td>53 (38–62)</td>
<td>0.554</td>
</tr>
<tr>
<td>*Mandibulectomy volume (cm$^3$)</td>
<td>11.8 (9.6–14)</td>
<td>12.6 (9.6–15.7)</td>
<td>15 (11.6–18.4)</td>
<td>0.369</td>
</tr>
<tr>
<td>Involved mandibular segments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Condyle (C)</td>
<td>33</td>
<td>1</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>• Body of mandible (B)</td>
<td>9</td>
<td>19</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>• Ramus (R)</td>
<td>8</td>
<td>6</td>
<td>1</td>
<td></td>
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<tr>
<td>• Symphysis (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• C and R</td>
<td></td>
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<tr>
<td>• B and R</td>
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<tr>
<td>• S and B</td>
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<tr>
<td>• C, R, and B</td>
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<tr>
<td>• B, S, and B</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>• R, B, and S</td>
<td></td>
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</tr>
<tr>
<td>*Fibula segment length (cm)</td>
<td>8.9 (8-9.8)</td>
<td>9.5 (8.4–10.6)</td>
<td>10.2 (8.5–11.9)</td>
<td>0.347</td>
</tr>
<tr>
<td>*Surgical time (minutes)</td>
<td>340 (335–355)</td>
<td>480 (450–487)</td>
<td>625 (615–642)</td>
<td>0.000</td>
</tr>
<tr>
<td>*MFFF ischemia time (minutes)</td>
<td>60 (59–65)</td>
<td>90 (84–94)</td>
<td>113.5 (109-119.5)</td>
<td>0.000</td>
</tr>
<tr>
<td>Onsite adjustments (in surgery)</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0.534</td>
</tr>
</tbody>
</table>

*Values are expressed in medians and 95%CI (low-sup). & Last follow-up assessment; MFFF: Microvascular free fibular flap; OSM: osteseosynthesis material (implant).
<table>
<thead>
<tr>
<th></th>
<th>3</th>
<th>4</th>
<th>3</th>
<th>0.798</th>
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</thead>
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<tr>
<td><strong>Number of compromised mandibular segments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complications</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>0.798</td>
</tr>
<tr>
<td>• Surgical wound infection</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>• OSM rejection</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Follow-up time (months)</strong></td>
<td>12.5 (15.4–25.5)</td>
<td>14.5 (14.6–35.7)</td>
<td>37 (18.7–48.7)</td>
<td>0.129</td>
</tr>
<tr>
<td>Lost during follow-up</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Tumoral recurrence</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>0.616</td>
</tr>
<tr>
<td><strong>Diet</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Regular</td>
<td>30</td>
<td>16</td>
<td>6</td>
<td>0.582</td>
</tr>
<tr>
<td>• Soft</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>• Nasogastric tube</td>
<td>13</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Oral communication</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>• Clear communication</td>
<td>30</td>
<td>15</td>
<td>8</td>
<td>0.285</td>
</tr>
<tr>
<td>• Non-clear communication</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>• Impossible oral communication</td>
<td>14</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Aesthetic appearance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Excellent</td>
<td>36</td>
<td>16</td>
<td>10</td>
<td>0.383</td>
</tr>
<tr>
<td>• Fair</td>
<td>11</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>• Deficient</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Facial symmetry</td>
<td>47</td>
<td>19</td>
<td>11</td>
<td>0.298</td>
</tr>
</tbody>
</table>

*Values are expressed in medians and 95%CI (low-sup). & Last follow-up assessment; MFFF: Microvascular free fibular flap; OSM: osteosynthesis material (implant).

Images of a case involving an 18-year-old woman with a myxoma affecting the body and ramus of the mandible and the computer-aided surgical planning are presented in Figs. 7 to 9.

**Discussion**

The digitally planned mandibular reconstructions to correct defects with MFFF due to oncologic resections showed high accuracy and satisfactory results. The adequate functional and aesthetical
results, with a high rate of facial symmetry achievement, are clinical indicators of the complete DSP's accuracy independently of the number of compromised mandibular segments.

The virtues of DSP and custom-made guides and plates for mandibular reconstructive surgery have been explored through different approaches; descriptive outcomes, comparative assessment with conventional surgical planning, presurgical and postsurgical accuracy comparisons, among others (6, 10, 14–16, 20, 22, 23, 25, 26). The general conclusion has been that CAD/CAM techniques improve efficiency during the preoperative planning and through the surgery given by the accuracy of fibular and mandibular cutting guides with a positive impact on the contouring symmetry more challenging to achieve with the traditional freehand technique (10, 14, 16, 20, 23, 25).

Oncological surgical management aims to resect the tumoral tissue while reconstructing the resultant defect. Mandibulectomies frequently create extensive defects leading to significant aesthetic deformities and functional impairment that can affect patients' speech and the ability to swallow (5, 7, 24, 27–29). Hence, it is expected that more prominent defects with more than two compromised mandibular segments would have worse or unpredictable outcomes. Additionally, the longer the fibula flap must be to restore the anatomy, the higher the donor site complications and worse outcomes.

Our report's novelty lies in the analysis of surgical variables and mid and long-term outcomes according to the number of resected and reconstructed mandibular segments.

Half of our patients presented mild defect sizes; in 55.5%, only one mandibular segment was involved, which could have favored the overall satisfactory outcomes. As expected, we observed a proportional increase of the resected mandibular volumes and harvested fibula segment lengths with the number of compromised mandibular segments. However, the lack of differences among those measurements could indicate that the DSP's precise calculations avoided unnecessary bone resections and fibula harvesting, minimizing the defect size and optimizing the tissular use.

DSP facilitates both the mandibular resections and the fibular harvest without the necessity for intraoperative adjustments nor freehand contouring, preventing prolonged vascular interruption to the flap (4, 23, 24). Previous studies have estimated the total surgical time and the MFFF ischemia time for both conventional and computer-aid planned mandibular reconstruction, showing the latter's advantage in terms of time-saving (1, 5, 25, 28). Bosc et al. (2016)(25) and Saini et al. (2019)(15) estimated a mean total operating time of 422 and 639 minutes, respectively, using computer-aid planning (25). Tasitano et al. (2016)(5) and Blanc et al. (2019)(20) showed a mean surgical time of 550.5 and 529 minutes for the conventionally planned reconstructions, compared to 435 and 441 minutes with DSP, respectively. In our case, the median surgical time for the whole cohort was 380 minutes, ranging from 340 minutes for one mandibular segment to 625 minutes for more complicated procedures of three compromised segments.

In terms of MFFF ischemia times, Succo et al. (2014)(1) and Rustemeyer et al. (2015)(28) observed a mean ischemia time of 105 and 98.6 minutes in the conventional group compared to 75 and 70.7 minutes for the DSP, respectively. In our cohort, the observed median ischemia time was 76 minutes that
ranged from 60 to 113 minutes according to the mandibular segments, comparable to those previously reported for DSP.

The custom-made guides optimized the operative times and facilitated the planned osteotomies to be replicated during surgery (5, 6, 22). In our study, most of the surgeries were accurate, showing a good correlation and excellent fit between the preoperative virtual 3D models and the procedure's results. Bony contacts of the fibula segments were adequate, and the flaps fitted precisely into the defects. We obtained 95.5% intraoperative accuracy that, in the end, rendered excellent results in the mid and long-term. Four patients required minor onsite modifications, probably due to intraoperative changes on the resection extension because of tumor expansion or reduction due to neoadjuvant therapy.

The mandibular reconstructions' primary goals are achieving facial symmetry or an acceptable aesthetic appearance and an adequate function (5, 10, 27–29). In our sample, the overall functional results indicated that more than 60% of the followed patients had preserved speech and masticatory function. Additionally, the general appearance was excellent in 74% of the patients, and the facial symmetry was achieved in 92%. These results were not affected by the number of compromised mandibular segments, indicating that good functional and esthetic outcomes can be expected with computer-aided surgical planning, even in more complicated cases.

Our technical solution for the full DSP and the customized design of the guides and implants in our patients showed precision and reliability during the actual procedure. Furthermore, the stratified analysis by the number of compromised mandibular segments showed no significant differences in the overall outcomes, indicating that our DSP was accurate and produced suitable results independently of the procedure's complexity.

This study's limitations include its retrospective nature and the consequent selection bias, and the inability to carry out a longitudinal follow-up due to poor adherence of patients to the standardized postoperative clinical evaluations. Since most of our cases are planned and performed with DSP, we did not compare our findings with conventionally planned mandibular reconstruction. Even though this is a widely used technology for complex surgical procedures in our setting, there are no similar literature reports regarding sample size, length of follow-up, and demographics.

**Conclusion**

The DSP for mandibular reconstruction secondary to tumoral resection showed satisfactory mid and long-term functional and aesthetical outcomes independently of the compromise's extension and complexity. The computer-aid surgical planning allowed the native anatomy to be restored, as close as possible, to the baseline state by utilizing customized surgical guides for rapid and precise sectioning of the fibula and fabrication of personalized implants for optimal and efficient segment repositioning.

**List Of Abbreviations**
Declarations

**Ethics approval and consent to participate.** The ethics committee and institutional review board at Instituto de Cancerología IDC Las Americas approved the study (04-2019, March 27/2019), and the guidelines from the Helsinki Declaration were followed.

**Consent for publication:** Written consent, in a pre-established format used by our company, was obtained from the patient whose case was used for figures 1-3. The consent form was sent through email and returned, signed by the patient.

**Availability of data and materials.** The datasets generated and analyzed during the current study are not publicly available due to corporate policies but are available from the corresponding author on reasonable request.

**Competing interests:** "The authors declare that they have no competing interests."

**Funding:** No funding was required for this study.

**Authors' contributions:**

Oncologic head and neck surgery group: Conception and design of the study, supervision of the study execution, and drafting and editing of the manuscript.

TECHFIT Digital Surgery: Data acquisition and interpretation, informed consent form procurement, drafting, and editing of the manuscript, corresponding author.

**Acknowledgments:**
Oncologic head and neck surgery group collaborating authors:

- Camilo Arango Peña. DDS. Maxillofacial surgeon. ORCID 0000-0002-5063-5149
- Juan Fernando Lopera. Plastic and microvascular surgeon. ORCID 0000-0001-9401-7855
- Andrés Rojas. MD. Head and neck surgeon. ORCID 0000-0002-3429-2844
- Joel Arévalo. MD. Head and neck surgeon. ORCID 0000-0003-1782-0614
- Julio Ruiz. DDS. Maxillofacial surgeon. ORCID 0000-0002-6322-2968
- Sergio Zuñiga. MD. Head and neck surgeon. ORCID 0000-0002-9903-8548
- Carlos Simón Duque. MD. Head and neck surgeon. ORCID 0000-0002-0289-0399
- Zaki Taissoun. MD. Head and neck surgeon. ORCID 0000-0002-5709-0372
- Alejandro Arango. DDS. Maxillofacial surgeon. ORCID 0000-0002-1388-4605
- Maria Fernanda Palacio. MD. General surgeon. ORCID 0000-0001-5601-3204
- Sabrina Gallego. MD. Plastic and microvascular surgeon. ORCID 0000-0002-7913-5148

TECHFIT Digital Surgery collaborating authors:

- Mauricio Toro. MSc. CEO/Co-Founder. ORCID 0000-0002-5302-1089
- Daniel Restrepo. Coordinator. ORCID 0000-0003-4230-4371
- Aura Cardona. Technical chief. ORCID 0000-0002-5392-1845 (Corresponding author)
- Alejandro Medina. B. Eng. Research coordinator. ORCID 0000-0002-3918-4930

References


Figures

Figure 1

DICOM images converted to 3D models
Figure 2

STL files of 3D models
Figure 3

Planned mandibular resection and osteotomies

Figure 4
Resulting mandibular defect after tumoral resection

**Figure 5**

Fibula superimposed on the mandibular defect to plan contour with fibular segments

**Figure 6**

Cutting guides' design
Figure 7

Initial photographic record, panoramic X-rays, and 3D reconstruction. The facial images (upper row). The radiographic projection (middle row) and 3D reconstruction from tomographic images (lower row) depict a tumor (myxoma) compromising the right body and ramus of the mandible producing a calculated bone defect of 11.6 cm³ after the resection.
Figure 8

Digital surgical planning and 3D modeling. The different images display the digital surgical pathway designed using the Mimics Innovation Suite. Upper row: the digital customized cutting guides designed and then placed on the 3D model. Middle row: the reconstructive scenario with the indicated bone resection through the osteotomy lines and the fibular free flap to create the neomandible, as well as the customized titanium plate secured to the 3D mandibular model. Lower row: the fibula segment of a calculated length of 5.61 cm for the planned reconstruction.
Figure 9

Postsurgical photographic record and postoperative 3D reconstruction. The pictures display the patient's appearance 60 months after the reconstructive surgery, showing satisfactory facial symmetry and excellent aesthetic appearance. The postoperative 3D reconstruction obtained from tomographic images (lower row) shows stable contact between bone segments and proper alignment.