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Construction of non-linear mandibular resection guides using two different software sets: A technical note

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Abstract

Numerous pathological disorders with widely differing origins and characteristics can affect the human jaws. These lesions can range from benign, but locally aggressive, lesions like ameloblastoma and odontogenic myxoma, to extremely destructive, potentially fatal lesions like malignant squamous cell carcinomas and osteosarcomas. The preferred method for managing these aggressive lesions is radical resection with suitable safety margins, ideally with immediate reconstruction whenever possible. It is of utmost importance that the surgeon finds the correct balance between being aggressive enough to ensure the removal of all tumor cells, and conservative enough to minimize the sacrifice of healthy tissue. The introduction of surgical guides in the field of maxillofacial surgery improved the accuracy of the operations and saved surgical time. The aim of this paper is to provide a highly detailed step by step guidance on the analysis, treatment planning, designing, and manufacturing of tailor-made resection guides using two sets of different softwares. A case report will then be presented showing the usage of a resection guide designed with this method.

Keywords: Pathological conditions, resection, tailor-made resection guides, computer-assisted surgery (CAS)

Introduction

The mandible can be affected by a myriad of pathological conditions, with widely varying origins and characteristics. These lesions may be as innocuous as simple small odontogenic granulomas and cysts of inflammatory origin, to benign, but locally aggressive lesions as ameloblastoma and odontogenic myxoma, ending with widely destructive, life-threatening lesions as malignant squamous cell carcinomas and osteosarcomas [1]. For the later groups, radical mandibular resections with appropriate safety margins, preferably with immediate reconstruction when applicable, is the technique of choice for management of these severe cases [2]. For the past 20 years, the advent of CT technology, and the following advances in computer science, have come together to create the field of Computer-Assisted Surgery (CAS), and incrementally change our profession forever. Virtually, all fields of oral and maxillofacial surgery have been touched by CAS, including implantology, traumatology, orthognathic surgery, congenital deformities, and of course, pathologies requiring resection/reconstruction surgeries [3, 4]. In 2015, Wilde *et al.* published a multicenter study on 30 patients receiving computer-guided resections using “keyhole” resection guides and reconstruction using patient specific implants. They concluded that “Mandibular reconstruction with PSMPs (Patient Specific Mandibular Reconstruction Plates) offers a broad range of opportunities and benefits compared with standard procedures and should be preferred where time and resources allow” [5]. Hwang *et al.* in 2020 introduced tailor-made non-linear resection guides and found that to be an equally safe less invasive option for mandibular resections [6].

However, in most published reports, the surgical teams depend on third party companies, and web meetings with biomedical engineers to virtually plan the surgical procedures, design the cutting and drilling guides and custom plate, manufacture them, and ship them for delivery. This adds time and financial constrains to the treatment plan, and deprives the surgical team of significant insights the could've made had they planned the case themselves [7]. The aim of this paper is to provide a highly detailed step by step guidance on the analysis, treatment planning, designing, and manufacturing of tailor-made resection guides using two sets of different softwares, one paid, and another completely free, so that surgical teams can alleviate these concerns, by the means they find best-suited to their situations.

A case report will then be presented showing the usage of a resection guide designed with this method.

Methods

The first software package comprises in Vesalius and Autodesk Meshmixer. These are completely free software's available for download from their websites,

<https://www.cti.gov.br/invesalius> and

<https://www.meshmixer.com> respectively.

InVesalius is a medical imaging program for 3D reconstruction, utilizing DICOM files from MSCT, CBCT, MRI, or any other imaging modality. The steps are as follows.

- Open InVesalius 3 software, click on "Import medical images" and browse for the DICOM files of the MSCT data of the patient, let it load, then click "Import".
- From the "Create new mask" menu, select the set threshold values for Bone, or manually edit them to best represent the patient's hard tissues.
- Use the "manual edition" tool and the Erase function to manually separate the mandible from the rest of the scan in all slices, then select "Create surface".
- You will notice a 3D render of the mask appearing in the volume window. From the "Configure 3D surface" tab, choose the "select region of interest" tool, and click on the mandible on the Volume window. All unconnected volume sets should disappear, and you will be left with a new surface comprising only the mandible.
- Create a new mask for the lesion. Manually set the threshold so that the upper and lower limits are the maximum values, and the mask is mostly empty. Use the manual edition tool, this time with "Draw" and trace the boundaries of the lesion in all slices.
- Repeat the previous steps, so that you now have two surfaces, one for the Mandible, and one for the Lesion. Select both of them, choose the "Export data" option, "Export 3D surface", and choose the destination for the STL files. This concludes the role of InVesalius 3 in this workflow.

Meshmixer is a software for working with triangle meshes, cleaning up CAD files, and designing and preparing 3D objects for 3D printing. The steps of using it are as follows.

- Open Meshmixer and Import the Mandible and Lesion STL files exported from InVesalius. A prompt will ask if you would like the software to shift their position. You should decline, in order to keep the DICOM Coordinates of the objects unchanged, to import them back and superimpose them on the CT scan, should you feel the need to.
- Use the Inspector tool in the Analysis tab to fix any problems with the meshes. Use the "Make Solid" tool in the Edit tab to fill out any voids in the interior of your objects. The combination of these two tools simplifies the meshes and makes them easier to work with and calculate more complex operations. It is therefore recommended they are repeated throughout this workflow.
- Use the Select tool and mark the entire surface of the Lesion object. Then select "Edit" from the pop-up menu, and choose "Offset". In the distance, write in the recommended safety margin for the specific lesion to be excised. For Ameloblastoma for instance, safety margin is recommended to be 15 mm.
- Duplicate the Mandible object, and repeat the previous step for the duplicate object, only this time, setting the offset to 2 mm, which will be the thickness of the resection guide.
- Select the Mandible 2 mm offset object, then press the "Shift" key and also select the Lesion Offset" object. From the Edit menu, select the "Boolean Difference"

option.

- From the Select menu, mark the area of the guide shell you want to keep acting as the surgical guide, then choose "Modify" and "invert". Press Delete to remove all the selected areas.
- If provided by the manufacturer, you can import an STL file for the screws used to fix the guide, or drilling for a Patient Specific Implant. You can also drop a cylinder from the "Meshmixer: Menu and enter the dimensions of the screws you plan to use. Use "Boolean Difference" tool as described earlier to incorporate the screw holes within the guide.
- Export the final guide in STL format, and it is now ready to be printed using any desktop 3D printer.

The second software package comprises Mimics Innovation Suite and Materialise 3-matic Medical softwares by Materialise. These are paid, state of the art software packages for Virtual Surgical Planning in various medical fields. More information can be found in their website, <https://www.materialise.com>

The steps are as follows

- The DICOM files are imported into Mimics Medical 19.0 software.
- Using the "Thresholding" tool, the range of Hounsfield Unit sets is chosen to highlight the mineralized structures and separate them from the rest of soft tissue structures in the scan creating a new mask.
- Using the "Split Mask" tool the mandible and the skull are separated into a separate mask.
- Using the "New Mask" tool, a new mask is created. Both the minimum and maximum threshold values are set to the maximum to create an essentially empty mask. Using the "Multiple Slice Edit" and "Region Growing" tools, the extent of the lesion is traced manually.
- Using the "Calculate 3D" tool on the new masks, a 3D rendering of the facial mineralized structures and the lesion are created.
- The Standard Tessellation Language (STL) files are then imported into 3-matic Medical 14.0 Software for further preparation.
- The models are refined using the "Fix Wizard", "Smoothing" and "Wrap" tools.
- The Midsagittal Plane (MSP) is constructed using the Anterior Nasal Spine, Nasion, and Basion points. Using the Mirror tool, the mandible is mirrored around the MSP. "N-Point Registration" and "Global Registration" Alignment tools are used to better align the mirrored Mandible to the original Mandible.
- Using the "Offset" tool in the Design menu, the Lesion object is expanded depending on its nature to visualise its safety margin. For example, in a case of Ameloblastoma, the offset should be set to 10-15 mm.
- Using Boolean Operations, the Lesion Offset can be subtracted from the original mandibular STL file to create the remaining bones after simulated resection, and it can also be intersected with the mirrored mandible to simulate the mandible without the lesion (Neomandible). This object can be later 3D Printed for pre-bending of a reconstruction plate, or it can be used in the design of a Patient Specific Implant (PSI)
- Using the "Offset" tool again, this time on the Mandible, a 3 mm thicker object can be created. Using the "Remove Undercut" tool, it is made to fit on the original mandibular body. It can be then cut using the offset lesion, and trimmed, creating the final Resection Guide.
- The resection guide along with the model can then be exported in STL format. The exported STL file for the

surgical guide is 3D-printed.

Case Report

A 50-year-old male with non-contributing medical history reported to the department of oral and maxillofacial surgery complaining of a facial swelling affecting left side of the face. The swelling was painless, with a gradual onset and a prolonged duration, and was first noticed 2 years earlier. A MSCT scan was ordered, and showed a multilocular, well-defined radiolucent lesion in the left mandibular body and ramus, extending posterior to the left mental foramen, to the mandibular angle, and reaching the mid ramus. An incisional biopsy was taken for the lesion under local anesthesia via an intraoral approach, based on which, the lesion was diagnosed as a Central Giant Cell Lesion. Initially, conservative treatment was tried in the form of intra-lesional steroid

injections and subcutaneous Calcitonin injections. A 3-Months follow-up MSCT scan showed poor response with an increase in the lesion dimensions. The case was therefore planned for resection.

The case was virtually planned using the Mimics Innovation Suite and 3-matic Medical softwares by Materialise as previously described with a safety margin of 5mm. The surgical guides and the mandibular model were 3D printed. A reconstruction plate was present using the mandibular model. Access was carried out through a submandibular approach and the guides fixated on the mandible using miniscrews. The osteotomies were carried out using Piezotome, and the segments were fixed using the prebent reconstruction plate. The wound was then closed primarily. Patient recovery was uneventful. (Figure 1).

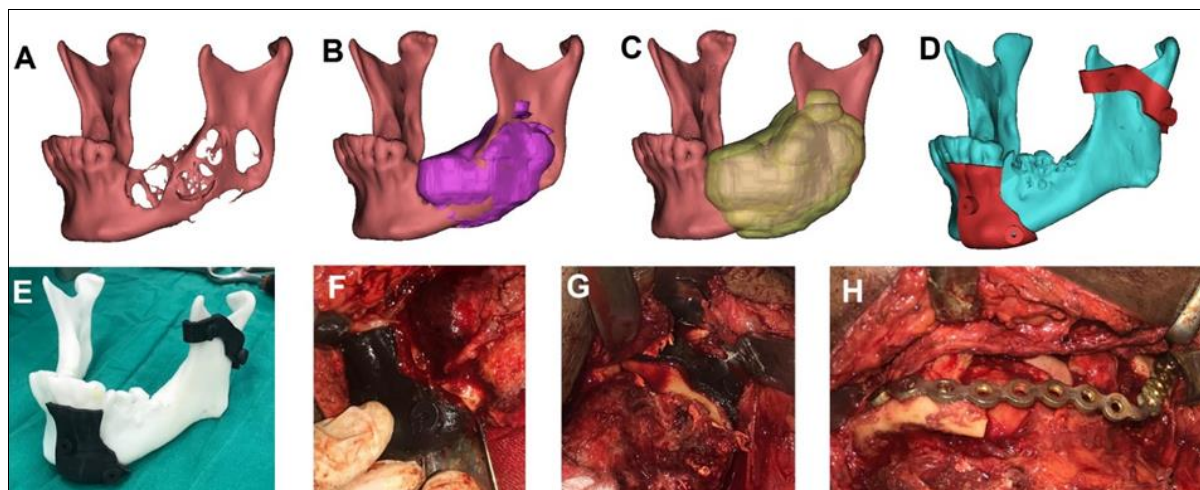


Fig 1: (A) Virtual model showing the mandible. (B) Virtual model showing the lesion. (C) Virtual model showing lesion with safety margin. (D) Virtual model showing designed resection guides. (E) 3D Printed mandibular model and resection guides. (F) Anterior guide fixed in place. (G) Posterior guide fixed in place. (H) Resection complete and segments fixated with prebent reconstruction plate

Conclusion

The intricate nature of mandibular pathologies necessitates precise surgical interventions. Recent advancements in Computer Assisted Surgery (CAS) have revolutionized mandibular resections by enabling personalized treatment plans and enhancing surgical precision. The integration of free and paid software tools provides accessible solutions for designing tailor-made resection guides, ultimately facilitating safer and more effective procedures. By leveraging CAS technology, surgical teams can optimize patient outcomes while minimizing procedural complexities and resource constraints.

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