

Fundamentals of Digital Treatment Planning

- DICOM:
 - Digital Imaging and Communication in Medicine
 - File extension is .dcm
 - Universally adopted medical imaging standard
 - It's the most common format for file storage, exchange and transmission of medical imaging, including CT scans, MRI, Ultrasound etc.
 - DICOM files contain embedded patient information/demographics and thus are displayed when using any imaging software (ex. Name, DOB, Gender, MRN). It also contains information on the type of equipment used and settings on the modality.
 - CT images are composed of numerous cross sectional slices. Each of these cross sectional slices correspond to a single .dcm file (that is why a single scan will contain numerous .dcm files in its data set).

- Segmentation:
 - Once the DICOM files are loaded into an image viewing software (such as Dolphin 3D), the area of interest must be highlighted to subsequently perform a 3D rendering that can be utilized for printing/planning purposes.
 - This involves segmentation (isolating region of interest) and denoising (removal of artifact- such as metallic scatter from dental restorations)
 - Can be done via 3 different methods:
 - Manual: operator highlights the area of interest slice by slice
 - time consuming but most accurate method
 - Semi-automatic: operator sets the threshold interval (in Hounsfield units) that guides the automatic 3D rendering process.
 - most 3D imaging software utilize this method
 - Automatic: AI, through its deep learning paradigm, uses convolutional neural networks (CNNs) to perform automatic CT segmentation.
 - area of current research

- Hounsfield Unit (HU):
 - A measure of radiodensity used in the interpretation of CT images.
 - The absorption of radiation by the particular tissue is converted into a grayscale image for viewing purposes.
 - Bone will have a large Hounsfield value (appears more white); whereas air has a small value (thus appearing dark).
 - When performing CT segmentation for orthognathic surgery purposes, we set the threshold interval for visualization of osseous structures vs. airway analysis for example.

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- STL:
 - Standard Tessellation Language
 - File type is .stl
 - File format that describes the surface geometry of a 3-dimensional object by using a series of linked triangles.
 - The more triangles, the higher resolution the 3D object will have
 - Most commonly used file format in additive manufacturing (ie. 3D printing)
- IOS:
 - Intraoral scanner
 - Used to take digital impression of the dentition
 - Scanner takes 10-25 pictures per second, CPU stitches the images together to form a 3D representation of the data.
 - The scanning software is able to generate an STL file that can be used for 3D printing and/or digital planning

Additive Manufacturing Technology

- SLA:
 - Stereolithography
 - World's first 3D printing technology, invented in 1986 by Chuck Hull, who patented the technology and went on to become the founder of 3D Systems
 - Laser beam is aimed at a vat of resin, thereby selectively curing and solidifying a cross section of the object, layer by layer, through a process called photopolymerization
 - The liquid resin contains photosensitive thermoset polymers that are solidified after exposure to the UV laser
 - Form 3B printer can print a layer thickness of 25 um depending on the type of resin used (average human hair has a thickness of 50 um to put that into perspective!).
 - Results in extremely accurate objects
 - Disadvantage: Takes long for a laser point to trace the entire cross section of an object
 - Another printing method similar to SLA, called DLP (Digital Light Processing) printing, uses a digital light projector to flash a single cross-sectional image of the object in order to cure the resin, rather than tracing the cross-sectional area with the point of a laser. This results in faster printing speeds, but at the cost of accuracy and resolution (due to pixilation).

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- FDM:
 - Fused Deposition Modeling
 - Uses spools of solid thermoplastic filaments, which are melted and extruded through a nozzle, to build up the layers that create a final part.
 - Mostly used for prototyping parts
 - Cheapest type of desktop printer (starts at a few hundred dollars).
 - Lowest resolution and accuracy of commonly available printers (ie. not great for medical purposes).
- SLS:
 - Selective Laser Sintering
 - A laser is used as the source of power to sinter, or “bind”, powdered material (plastic, metal, ceramic or glass) to form a solid object.
 - Object is built layer by layer in a powder bed.
 - Since the surrounding powder bed supports the printed object, no additional support material is required.
 - Commonly used for industrial purposes due to strength of finished parts
 - Most of the opaque anatomic models we are provided by companies utilize this type of printing technology
 - Stryker Custom PEEK implants are also fabricated using SLS technology
 - DMLS (Direct Metal Laser Sintering): Used to make 3D printed metal parts
 - This technology is used by many companies to fabricate patient-specific plates for maxillofacial reconstruction and orthognathic surgery
 - Lots of material science but interesting to know and be aware:
<https://www.youtube.com/watch?v=fzBRYSiyxjl>
 - In the video, they discuss several issues with this technology such as metal porosity and crack propagation.
 - These drawbacks can be compensated for by increasing plate thickness in regions subjected to higher stress as identified from finite element analysis (such as the mandibular angle in reconstruction plates). Benefit of designing a patient-specific plate!

3D Printing Software

- Meshmixer:
 - “Swiss army knife for 3D meshes”
 - Can perform many functions such as:
 - Subtract portions of image not needed
 - Resize objects
 - Hollowing
 - Combining/merging images
 - Mirroring an object etc.

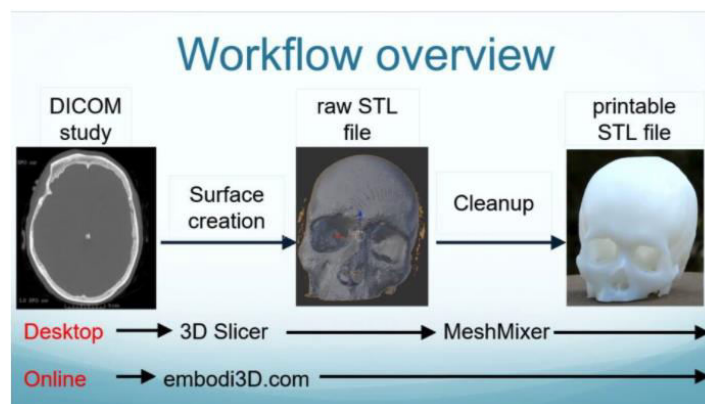
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- Example of CAD (computer-aided design) software that is open-source as well as free to download

Workflow for Printing Anatomic Models

- 1) Upload CT scan to 3Dslicer (www.slicer.org) to convert DICOM into NRRD (nearly raw raster data). NRRD files are anonymized and contain no sensitive patient information and is this a good file for transferring medical scan data while protecting patient privacy. Also, DICOM data sets contain hundreds of individual files, whereas NRRD files can store a medical scan in a single file.
<https://www.embodi3d.com/blogs/entry/341-how-to-create-an-nrrd-file-from-a-dicom-medical-imaging-data-set/>
- 2) Convert the NRRD file into STL format for 3D printing purposes using democratiz3D (Scroll down to Part 2):
<https://www.embodi3d.com/blogs/entry/428-3d-printing-tutorial-introduction-to-free-and-open-source-software-3d-slicer-meshmixer-democratiz3d-from-the-2018-rsna-meeting/>
- 3) Upload the STL file into Meshmixer for editing purposes. Can remove artifact, delete parts of scan not needed for printing purposes, can hollow out your model to save resin or solidify your model (if you plan to simulate surgery).
 - a. Hollow an object
(https://www.youtube.com/watch?v=LULZdV_w4lw)
 - b. Make an object solid
(<https://www.youtube.com/watch?v=vDhe4vJ95jQ>)



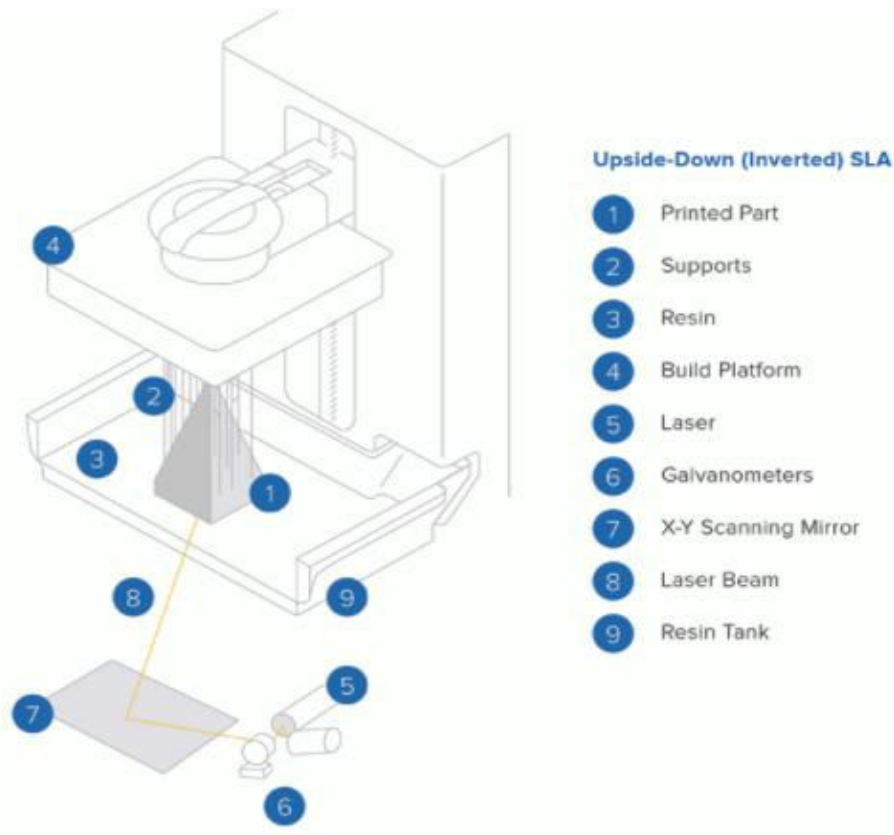
<https://www.embodi3d.com/blogs/entry/386-using-free-and-open-source-software-and-web-services-to-create-3d-printable-anatomic-models-from-medical-scans-workshop-from-the-2017-radiological-society-of-north-america-rsna-meeting/>

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- Preform:
 - Example of a “slicer” software (usually comes along with the 3D printer you buy)
 - Basically, software that allows the printer to “understand” the STL file you are about to print
 - It slices the 3-dimensional geometry of the STL file into thin 2-dimensional layers which is then converted into a long series of coordinates which the printer then utilizes to complete the printing process
 - Can change the orientation of the object on the build plate
 - Avoid “cupping” effect for hollow objects
 - Can move the object so that supports do not fall on areas of interest (ie. occlusal surfaces of teeth)
 - Need to add supports to reinforce overhanging structures during the printing process
 - Printing times are affected by object size, layer thickness (smaller layers will take longer to print), type of resin used (we use Draft V2 for anatomic models...fastest print)
 - https://www.making.unsw.edu.au/learn/3DPrinting_learning_modules/slicing-formlabs-preform-software/

- Formlabs 3D Printer:



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- Resins:
 - Resins vary by the specific monomers, oligomers, photoinitiators and organic/inorganic additives they contain.
 - Material properties that are influenced by the particular resin blend include:
 - Wavelength required for curing
 - Exposure time for solidification
 - Stiffness and strength
 - Highest possible resolution
 - Biocompatibility
 - Chemical and mechanical Resistance

- Post-processing:
 - Wash:
 - Isopropyl alcohol is agitated (with a propeller) in the washing tank to remove uncured resin from a print.
 - Cure:
 - In SLA, the resin is not completely cured at completion of the printing process
 - Post-curing is required to achieve the best mechanical properties of your printed part such as hardness and tensile strength
 - Post-curing is performed by placing the printed part in a curing box and subjecting it to intense UV light as well as elevated temperature
 - Removal of Supports, Finishing/Polishing
 - Its recommended to remove supports after the curing phase
 - More difficult to do at this stage, so for anatomic models we remove supports immediately after the wash step
 - For orthognathic splints it's advisable to remove supports after the curing phase is complete (to prevent potential distortion of splint)

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3D Printing for Orthognathic Surgery

Great YouTube video going through basic steps in Dolphin 3D Surgery module:

<https://www.youtube.com/watch?v=GKH3vyrFg>

- U of T Orthognathic Initial Evaluation Form:

Front:

The Toronto Protocol		Orthognathic Surgery Workup																													
Dr Marco Caminiti		Date _____ T3 _____																													
Patient: _____ M F DOB _____ age _____																															
Ortho: _____ Braces (type and duration) _____ previous ortho tx ? _____																															
Presented with: _____ CC: _____ records: _____																															
Orthodontic Exam: Class ____ I ____ II div 1 ____ II div 2 ____ III OB ____ % OJ ____ mm CR - CO shift ____ mm ____ Open Bite: anterior ____ mm posterior ____ mm Crowding: max ____ mand ____ Incisors: ____ proclined ____ retroclined missing teeth: _____ (date of removal: _____) prosthetics /fractured/peg teeth: _____ Wisdom teeth: _____ Major Contacts: _____		Symmetry R Glabella L Nose NT Ulip +1 -1 Llip Pog																													
Orthognathic Evaluation: <table border="1"> <thead> <tr> <th></th> <th>Maxilla</th> <th>Mandible</th> <th>Chin</th> </tr> </thead> <tbody> <tr> <td>Anterior Posterior</td> <td>_____</td> <td>_____</td> <td>_____</td> </tr> <tr> <td>Vertical</td> <td>_____</td> <td>_____</td> <td>_____</td> </tr> <tr> <td>Transverse</td> <td>_____ mm</td> <td colspan="2">measured at predicted Class I (+6 CP to -6 DB)</td> </tr> <tr> <td>Mentalis/perioral strain</td> <td colspan="3">_____</td> </tr> <tr> <td>CANT: pupil to fox plane: Right +/- _____ mm</td> <td colspan="3">Left +/- _____ mm</td> </tr> <tr> <td>YAW: buccal corridor</td> <td>_____ normal</td> <td>_____ excess</td> <td>_____ deficient</td> </tr> </tbody> </table>			Maxilla	Mandible	Chin	Anterior Posterior	_____	_____	_____	Vertical	_____	_____	_____	Transverse	_____ mm	measured at predicted Class I (+6 CP to -6 DB)		Mentalis/perioral strain	_____			CANT: pupil to fox plane: Right +/- _____ mm	Left +/- _____ mm			YAW: buccal corridor	_____ normal	_____ excess	_____ deficient	TMJ Evaluation: Hx:  Click Pop Pain Sublux R L R L R L R L	
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Esthetic Evaluation: Alar base _____ mm Mouth Width _____ mm Face Height (U/L) ____ / ____ mm Inner IC /pupil ____ / ____ mm Incisor Exp (rest/smile) ____ / ____ mm Upper lip length _____ mm (20/23) Lower Lip length _____ mm (48) Vermillion (rest/smile) ____ / ____ mm Interlabial Gap _____ mm (0-2) Nasolabial angle _____ N ____ acute ____ obt Malar prominence _____ N ____ def Paranasal _____ N ____ flat		Other: Dolphin: VTO:																													

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Back:

Treatment Plan

_____ 1. Presurgical Orthodontics

_____ 2. Transverse: SARPE

_____ 3. Extractions for crowding:

_____ 4. Extraction of 8s:

_____ 5. Orthosurg: Lefort _____ BSSO _____ Genio _____ Other _____

_____ Risk/Benefits/Complications discussed

Fees: A B C SARPE teeth ext:

Recon Jaw/2nd Consult Date: _____

Models: Plan: 1. book OR: _____ hrs

Confirm Letter: 2. _____ / _____ mth/yr

3.

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- U of T Orthognathic Pre-surgical Evaluation Form (example):

CLINICAL EXAM	Maxillary incisor show	Rest: 5
		Smile: 12
	Maxillary midline	0N mm R L
	Mandibular midline	mm R L
	Ocular dystopia	Describe:
	Cant	L mm R 1.5 mm lower
	Yaw	R L fullness
	Alar base	29 33 mm
	Paranasal/malar remarks:	
	Chin remarks:	
CEPHALOMETRICS	Angulation of Max Incisors	N Upright Proclined
	Occlusal Plane	N Flat Steep
	A-P Maxilla: Unit	N Prog Retro
	A-P Maxilla: mm to FFA	N Prog Retro
	A-P Mandible	N Prog Retro
	SNA,SNB,ANB – significant finding:	
	Wits and Overjet	0 wits 0J
SURGICAL MOVEMENTS	Holdaway	long
	Segmentation of maxilla	yes where
	Maxillary Central Incisor	Up 2 Down mm
		Ant Post mm
	Asymmetry of maxilla	Move 1 mm R L
	CANT of the maxilla	Move 2 cw ccw degr
	YAW correction in degrees	cw ccw deg
	Occlusal Plane in degrees	3 steepen flatten
	Mandible A-P (estimate)	Ant 3 Post
	Mandible Asymmetry (estimate)	Move 1 mm R L
Adjunctive	Genioplasty A-P & vertical in mm	ant post up/down
	Genioplasty (other)	volume
	Bone grafting	X ICG other
	TADS/MMF screws	X
	Tooth Extractions	X
Office	Other guides/stents/CAOS	X
	Prescriptions given to Patient	✓ Rx ✓ Kit ✓ POE
	Escort/Responsible Adult	
	Upload to DPC date:	
	Go TO Meeting date:	
Engineer:	✓ V-shape	

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- Dr. Caminiti VSP Algorithm:

Develop your own sequence of steps during virtual planning session.

The Toronto Protocol University of Toronto Centre for Corrective Jaw Surgery Digital Planning Sequence

1. Determine need for segmentalization and where to osteotomize pre DP
2. Check that Natural Head Position of the DPC is coincident to patient
3. Check Head tilt / Cant
4. MIDLINE corrected and marked
5. CANT: Rotate maxilla to correct cant (rotate around contact point of centrals)
6. Determine HINGE AXIS(prn)
7. CENTRAL INCISOR: Determine ideal position vertically and horizontally
8. OCCLUSAL PLANE: Adjust occlusal plane to central incisor angulation to pogonion position correlation
9. OCCLUSION: Fit mandible according to best occlusion (orienting segmentalized portions prn)
10. YAW: Worms view of maxillomand complex; worms view of Maxilla (yaw) and adjust prn; check bird's view for irregularities.
11. INTERFERENCES: Rotate proximal segments in place; look at interferences
12. Genioplasty and other procedures
13. Determine if mandible or maxilla first surgery
14. Describe splints (thin, thick, holes, shallow, moderate, deep cusp) and guides (genioplasty or downgraft shims)

remember Digital Planning/VSP/Proplan is a fancy articulator.... **clinical exam is the key and the veto**