Building a Workflow for Cooperatively Controlled Robotic Mandibular Surgery

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Clinical Motivation:

Mandibular osteotomy is a common procedure used to correct an overextended jaw or receding chin [1]. This is done by making a sagittal cut through either side of the mandible as shown in Figure 1 below. During this procedure, the physician must be careful not to damage the alveolar nerve that runs through the mandible [3]. Damage to this nerve can lead to numbness of the chin, lower lip, and lower teeth. According to Dr. Yang, 100% of patients experience a temporary neurosensory deficit following the procedure with 10% of those cases being permanent.

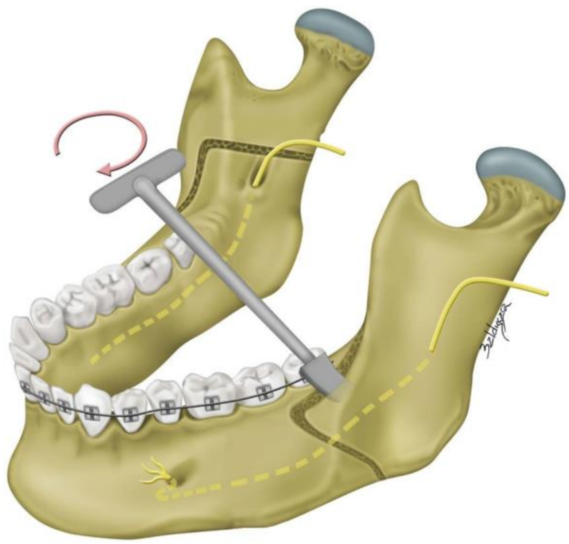

Figure 1. Sagittal cuts on either side of the mandible [2]

Possible solution:

The solution we will be investigating to solve this issue is the use of a cooperative robot to enforce virtual fixtures. Segmented CT data from the patient will be used to allow the robot to recognize the location of critical features such as the alveolar nerves. A “hand over hand” style robot can then work with the physician by reducing hand tremors, but also preventing them from passing the tool into the alveolar nerves. An example of a cooperative robot is show in Figure 2 below.

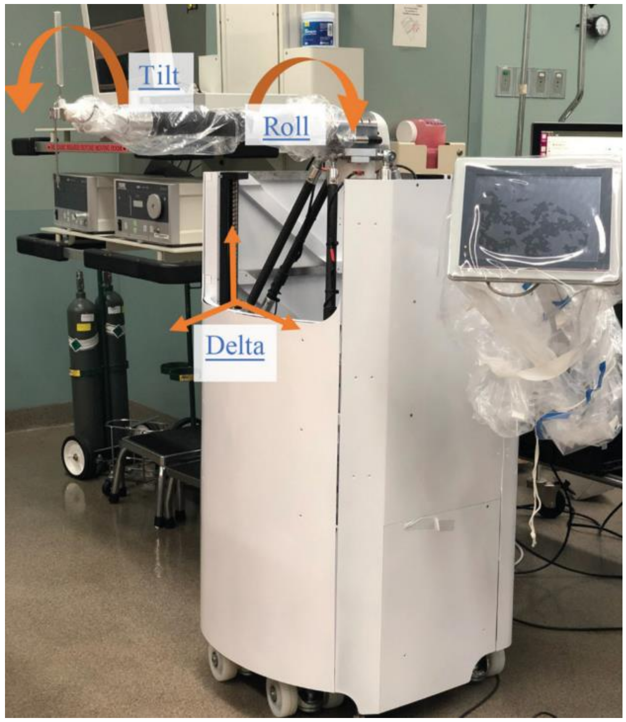

Figure 2. Galen Mark 2 "Hand Over Hand" style robot. [5]

Prior Work:

This project will build off some that has previously been done. CT data from 15 patients has been segmented to identify the mandible and left and right alveolar nerves. Images of one set of segmented models can be found in Figure 3 below. Regarding the virtual fixtures, most of this project will be building off a paper written by Max Li and others [5]. Here they developed a framework for generating virtual fixtures from an STL file. Figure 4 shows a series of models that were tested in their simulation ranging from simple to complex geometries.

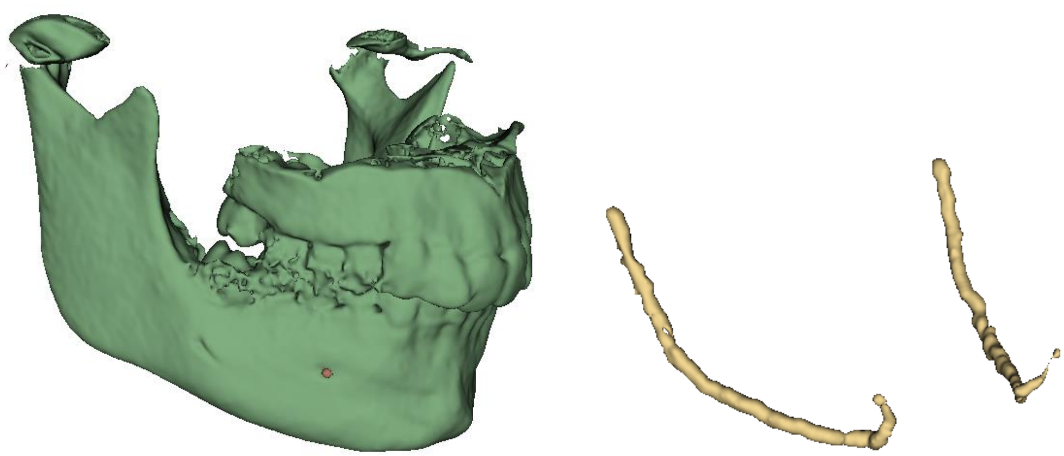

Figure 3. (Right) Segmented Mandible, (Left) Segmented Alveolar Nerves

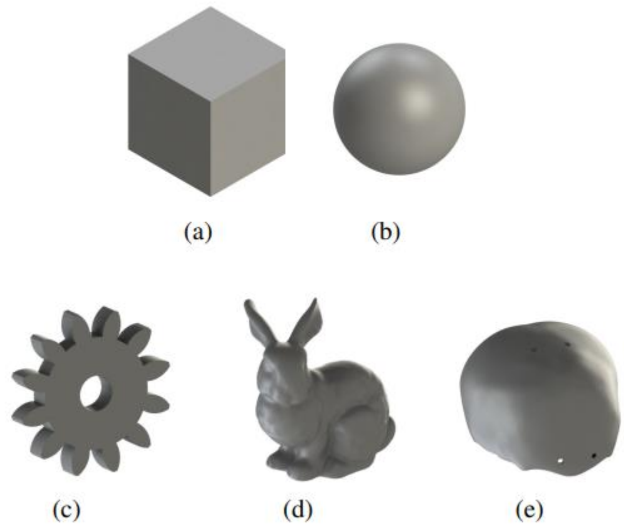

Figure 4. Models used in Max Li's virtual fixture framework [4]

Goals and Significance:

The main goal of this project is to establish a workflow for robot-assisted mandibular osteotomy with virtual barriers. If successful, this will be the first semi-autonomous robot-assisted mandibular osteotomy workflow. This workflow will improve patient safety and help to pave the way for future cooperative robot procedures.

Technical Approach:

This project will involve a variety of programs and tools for successful execution. Our plan involves utilizing the equipment described in the list below:

- Segmentation software: 3D Slicer
  - 15 models saved as NRRD files
- 3D Printing:
  - Software: GrabCAD, Simplify3D, Photon Workshop, Meshmixer, Fusion360
  - Machines: Stratasys F170, Flashforge Creator Pro, Creality CR-10, Anycubic Photon
  - Materials: ABS, PLA, Photopolymer Resin
  - Casting: Dental Stone
- Surgical Tool: J&J Drill Anspach EG1
- Robot: 5 DOF Galen Mark 2 in the mock OR
  - Additional software: ROS

The general approach for this project will first involve creation of the phantoms. 3D printing will be used to create mandibles along with molds and casts. Several 3D printing filaments, resins, and cast materials along with different model designs will be tested to develop a phantom that is bone-like when drilled. Registration of the model to the robot coordinate system will be done using an optical tracking system and fiducials mounted on the teeth and drill. The virtual fixtures portion of the project will be mostly built of the work done in the paper by Max Li [4] using STL models generated from the CT data to create the barriers.

Key Deliverables:

The deliverables for this project are summarized in the list below:

- Minimum
  - 3D printed phantoms that are drillable and similar in feel to bone
  - Documentation of clinical consultant approval
- Expected
  - Demonstrable cooperative control robot-assisted mandibular osteotomy
  - Documentation of clinical consultant approval
- Maximum
  - Documentation and demonstration of virtual fixtures for robot-assisted mandibular osteotomy

Timeline/Milestones:

The milestones for this project along with the expected timeline are summarized in the table below.

Milestones	Start	End
Mandible Phantoms	02/18	03/18
Galen configured for mandibular osteotomy	02/18	04/08
Registration with Galen	04/08	04/22
Virtual Fixtures Algorithm	05/13	06/03
Workflow Documentation	06/03	07/10

Dependencies:

Key dependencies for this project are analyzed in the table below. This will be used to ensure resources that could delay this project are addressed.

Dependency	Status	Fallback/Prevention	Need by	Effect
3D Printing Availability	Printer demand dependent	Personal 3D printers	Feb 28th	Delay in phantom creation
Mentor Feedback	Schedule dependent	Weekly meetings and early communication to avoid conflict	Mar 14th	Delay in phantom and Galen configuration
Drill and Drill Bits	Obtained	N/A	Feb 28th	Delay in Galen configuration
Galen accessibility	Schedule dependent	SharePoint calendar to schedule use	Throughout	Delay in all milestones
3D Segmentations suited for printing	In progress	Edit segmentations and use fewer models	Feb 21st	Delay in phantom creation
Dental stone for casting	Obtained	More can be acquired from Dr. Creighton	Feb 28th	Delay in phantom creation

Roles and Responsibilities:

As the only team member, Jesse Haworth will be responsible for all tasks. Dr. Yang and Dr. Creighton will advise on clinical aspects of the project with Andy Ding and Dr. Taylor offering their technical expertise.

Management Plan:

Project management will be controlled through weekly CiiS lab meetings on Wednesdays along with weekly project meetings with Dr. Yang on Tuesdays. Communications will mainly be held through slack and email. File sharing with be managed with SharePoint, OneDrive and email.

Reading List:

- Mandibular sagittal split osteotomy - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5392880/
- Kevin Olds' thesis on robots in otolaryngology - https://jscholarship.library.jhu.edu/bitstream/handle/1774.2/37927/OLDS-DISSERTATION-2015.pdf
- Bilateral Sagittal Split Osteotomy - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3805998/
- Inferior alveolar nerve injury following orthognathic surgery - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3094736/
- Max Li's paper on virtual fixtures - https://github.com/mli0603/PolygonMeshVirtualFixture
- ENT Microsurgery Robot - https://journals-sagepub-com.proxy1.library.jhu.edu/doi/full/10.1177/0194599819861526

References:

1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5392880/
2. https://www.researchgate.net/figure/A-modified-Obwegeser-Dal-Pont-bilateral-sagittal-split-osteotomy-BSSO-technique-was_fig3_335848383
3. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3094736/
4. https://github.com/mli0603/PolygonMeshVirtualFixture
5. https://journals-sagepub-com.proxy1.library.jhu.edu/doi/full/10.1177/0194599819861526