Validating and Improving Single-Stage Cranioplasty Prosthetics with Ground Truth Models

An expansion of single-stage cranial defect repairs and implants

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Background

Team: Erica Schwarz, Willis Wang

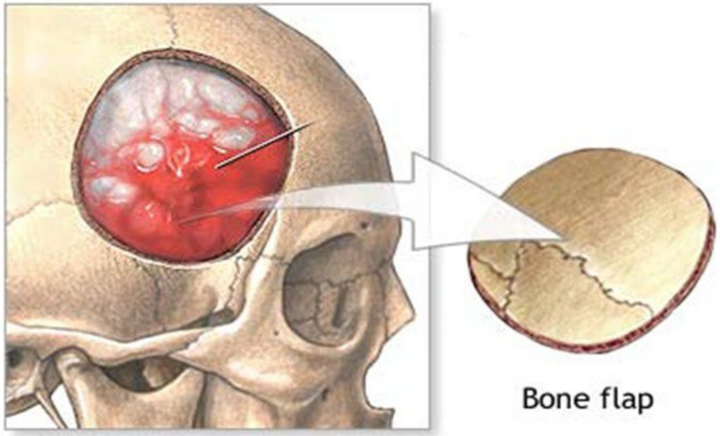
Mentors: Mehran Armand, Chad Gordon, Ryan Murphy

Affiliations:

1. Applied Physics Laboratory: Research and Exploratory Development Department
2. Johns Hopkins University: Department of Mechanical Engineering
3. Johns Hopkins University School of Medicine: Department of Plastic and Reconstructive Surgery
4. Johns Hopkins University School of Medicine: Department of Neurosurgery

Introduction

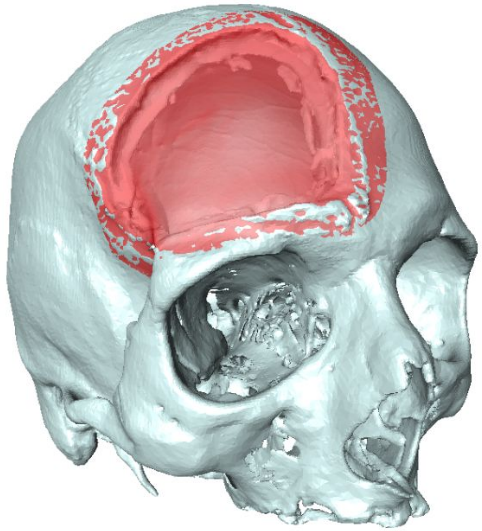
- Cranioplasties are used to reconstruct the site of craniotomies and other cranial surgeries that remove sections of the skull.
- Due to risk of infection after such a procedure, creating a well-fitting prosthetic is important for increasing quality of life and risk management.
- Customized Cranial Implants (CCI) use CAD and CT scans to provide a full-thickness reconstructions which are used to replace the sections of the skull removed during operation.



Current Issues

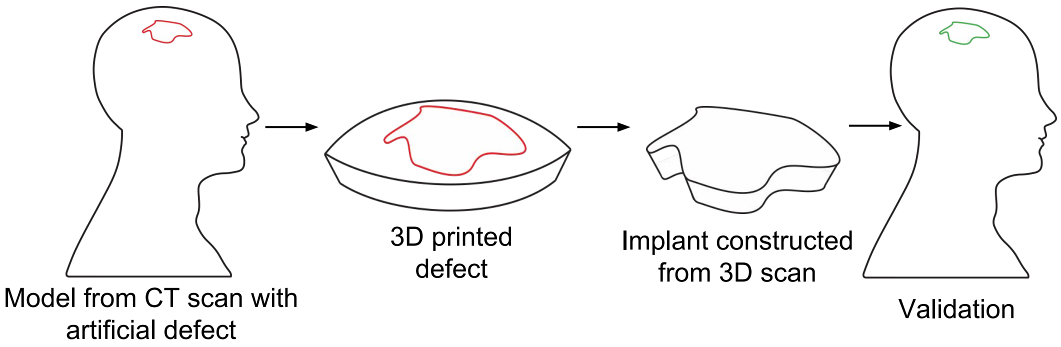
- Creating a prosthetic that perfectly fits the operative hole requires the patient to be brought back to the operating room at a second date (two-stage surgery).
- A single-surgery solution where the implant is created manually can take considerable amount of time (10 - 80 minutes) and be inaccurate.
- New methods that use an overhead projector to aid manual implant creation are limited by complexity of implant.
- System has been developed for using 3D scanner to create a machined single-stage implant, but...

- **Effectiveness of using 3D scanners and point cloud models to completely capture defect shape and bevel is currently unknown.**



Proposed Solution

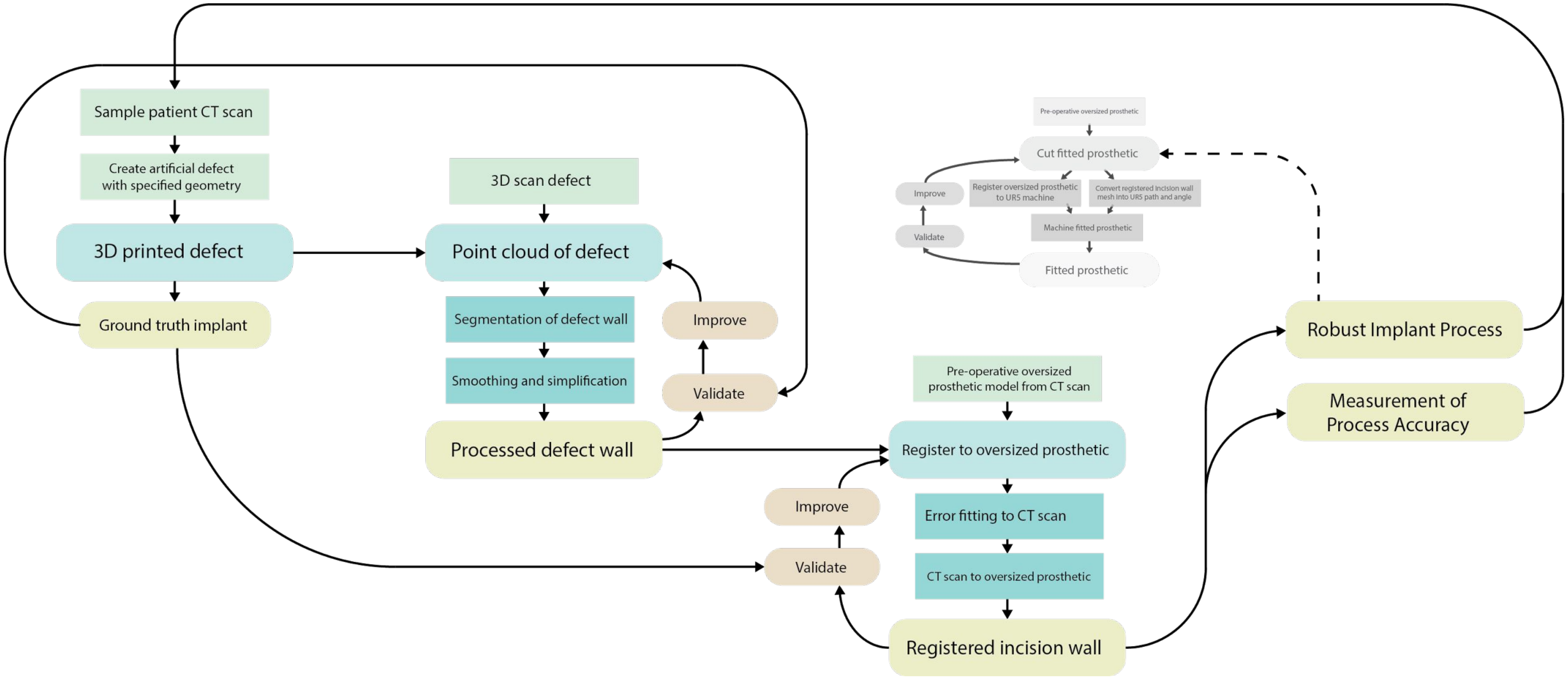
1. Use patient CT scan to create model of skull and ground truth defects of different shapes and complexities.
2. Fabricate physical representation of ground truth model.
3. Use a 3D scanner to make a point cloud representation of the defect site. A point cloud will be converted into a mesh of the defect through the patient's skull that incorporates defect shape, depth, and bevel.
4. Process the defect mesh's contours and register it to the defect model.
5. Validate and determine accuracy of mesh to defect fit.



Technical Summary

1. Use patient CT scan to create a patient-specific model of skull.
   a. Convert image stack into binary surface using lab program.
2. Create artificial defect using 3D modeling program.
   a. Subtract defined geometries from skull sections using Solidworks. Incorporate a range of bevels and shapes.
   b. 3D print defect and area surrounding it.
3. After ground truth defect is made, use a 3D scanner to make a point cloud representation of the defect site.
   a. Perform color and depth based segmentation of defect site.
   b. The point cloud will be converted into a mesh of the defect through the patient's skull.
4. Process the mesh's contours and register it to the oversized implant.
   a. Use a smoothing algorithm to eliminate noise and harsh angles on the interior wall of the defect.
   b. Find best fit of defect mesh's surface to surface of patient CT scan model and evaluate accuracy
5. Using a fabrication device, cut the oversized implant into the form of the mesh.
   a. Mesh representation must be converted into a machining path
   b. Oversized implant must be registered to machine space

Technical Approach



Deliverables

- Minimum
  - Segment and process point cloud of defect to create defect mesh
  - Register defect mesh to patient
  - Register mesh to oversized prosthetic
- Expected
  - Create ground truth models
  - Validate and improve process accuracy
  - Quantify accuracy of implant creation
  - Package process as Slicer module
- Maximum
  - Test process with cadavers
  - Register oversized prosthetic to UR5 machine
  - Define UR5 path for cutting fitted prosthetic

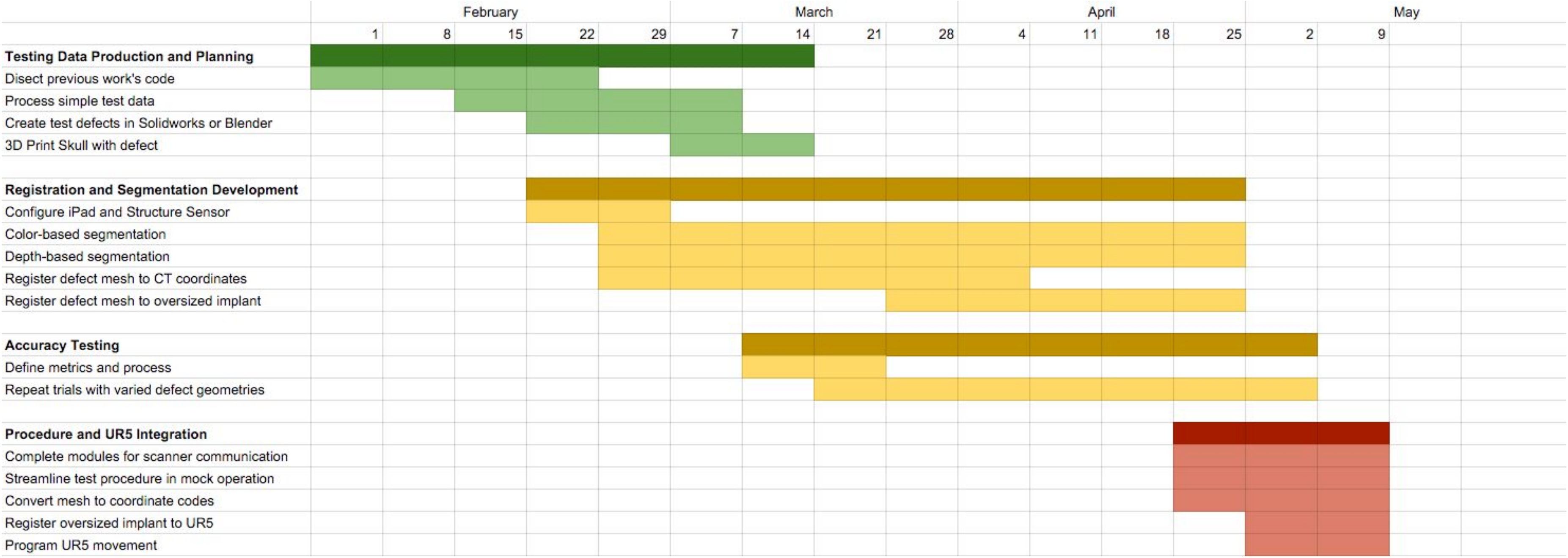
Dependencies

Status	Dependency	Description
Completed	Structure Sensor	Sensor to be used for scanning incision site. Provided by Dr. Armand.
Completed	iPad	iPad to use with structure sensor. Provided by Dr. Armand.
Completed	Software Repository	Provided by Ryan Murphy. Contains existing lab code, system, and test data.
Completed	Patient CT Scans	Will be used to create ground truth models. Provided by Ryan.
In Progress	3D Printer	Needed to fabricate ground truth models. DMC, BME Design Studio, or Shapeways.
In Progress	Operation Observation	Currently scheduling operation viewing to better motivate understanding of the problem.
On Hold	UR5 Machine	Machine for fabricating prosthetic. Not current priority.

Timeline

Date	Objective
2/15 - 3/14	Testing Data Production and Planning
2/22 - 4/25	Registration and Segmentation Development
3/14 - 5/02	Accuracy Testing
4/25 - 5/9	Procedure and UR5 Integration

Chart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Testing Data Production and Planning
Disect previous work's code
Process simple test data
Create test defects in Solidworks or Blender
3D Print Skull with defect
Registration and Segmentation Development
Configure iPad and Structure Sensor
Color-based segmentation
Depth-based segmentation
Register defect mesh to CT coordinates
Register defect mesh to oversized implant
Accuracy Testing
Define metrics and process
Repeat trials with varied defect geometries
Procedure and UR5 Integration
Complete modules for scanner communication
Streamline test procedure in mock operation
Convert mesh to coordinate codes
Register oversized implant to UR5
Program UR5 movement

Management

The division of labor for this project will be distributed equally with both team members working on all components of the project. However, the primary responsibilities of the two members will be as follows:

- Erica Schwarz: Refining defect point cloud processing (i.e. smoothing and deleting outliers, simplifying geometry for later machining). Creating robust ground truth models from test data.
- Willis Wang: Refining segmentation method of incision point cloud. Researching best ways to compare fit of meshes to ground truth.

Team meetings will be weekly on Wednesday mornings with additional meetings planned based on the discussion during that time. Meetings with Ryan Murphy will take place weekly on Thursday mornings to review progress.

Further Reading

1. Cates JE, Lefohn AE, Whitaker RT. GIST: an interactive, GPU- based level set segmentation tool for 3D medical images. Med Image Anal. 2004 Sep 8 (3):217-31.

2. Gordon CR, Fisher M, Liauw J, Lina I, Puvanesarajah V, Susarla S, Coon A, Lim M, Quinones- Hinojosa A, Weingart J, Colby G, Olivi A, Huang J. Multidisciplinary Approach for Improved Outcomes in Secondary Cranial Reconstruction: Introducing the Pericranial- Onlay Cranioplasty Technique. Neurosurgery. 2014 Jun 10 Suppl 2:179-89.

3. Herbert M, Pantofaru C. A Comparison of Image Segmentation Algorithms. Carnegie Mellon University 2005. The Robotics Institute

4. Huang GJ, Zhong S, Susarla SM, Swanson EW, Huang J, Gordon CR. Craniofacial Reconstruction with Poly (Methylmethacrylate) Customized Cranial Implants. The Journal of Craniofacial Surgery. 2015 Jan;26(1):64-70.

5. Murphy RJ, Wolfe KC, Gordon CR, Liacouras PC, Armand M, Grant GT. Computer-assisted Single-stage Cranioplasty. IEEE. Jan 2015.

Questions?