VetMed: Design and Mechanical Analysis of Patient-Specific Mandibular Reconstruction Implants

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Client: Dr. Graham Thatcher

And

Dr. Jason Bleedorn

Team Members

Team Leader: Will Wightman

Communicator: Laura Richmond

BSAC: Young Kim

BWIG: Cade Van Horn

BPAG: Kylie Gaspar

Figure 1: From left to right: Cade Van Horn, Kylie Gaspar, Will Wightman, Laura Richmond, Young Kim

Current Problems with Canine Mandibular Implants

- Not patient specific

- Stress on patient unknown

- Labor intensive process

- Approximation

- Resources not optimized

Figure 2: Different bite forces on different breeds of large dogs https://www.rottweilerlife.com/wp-content/uploads/2014/02/dog-bite-force.jpg
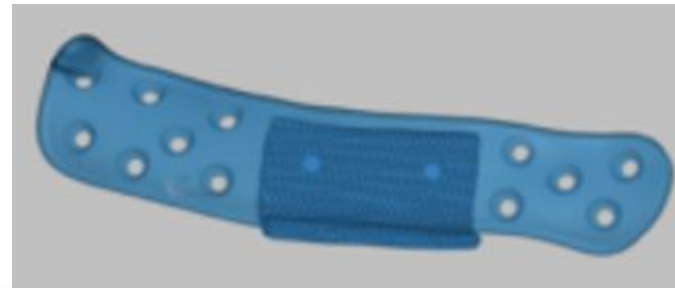

Figure 3: Current model of implant. The long piece is the titanium implant, the smaller darker piece is a titanium lattice to promote bone growth *[From client]*

Important Anatomy of Canine Jaw

- Jaw adductor muscles
  - Four main muscles control movement
- Temporomandibular joints
- Limited lateral movement
- Force transfers directly to teeth
- Nerves

[Kim, S., Arzi, B., Garcia, T. and Verstraete, F. (2018).]

Figure 4: Synovial Condylar Joint
https://www.studyblue.com/notes/note/n/classification-of-synovial-joints/deck/14906492

Figure 5: Canine X-Ray
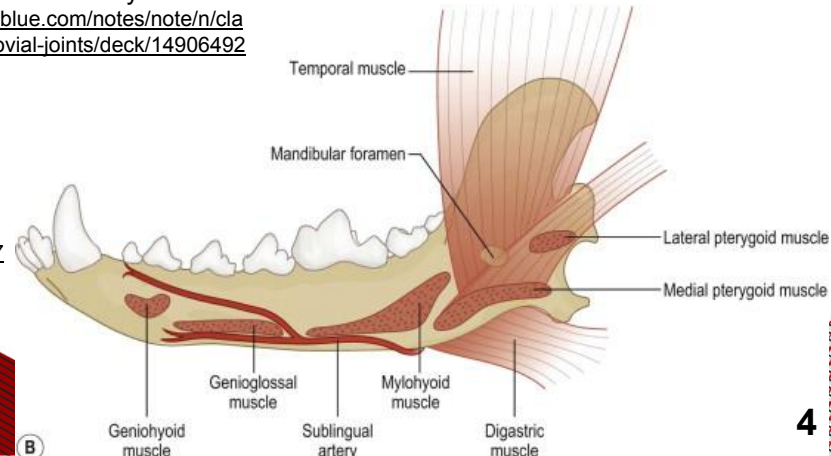https://assets3.thrillist.com/v1/image/2717375/size/tmg-article_tall.jpg

Figure 6:
Major muscles of canine mandible
https://ars.els-cdn.com/content/image/3-s2.0-B9780702046186000464-f046-003b-9780702046186.jpg?_

Temporal muscle
Mandibular foramen
Lateral pterygoid muscle
Medial pterygoid muscle
Geniohyoid muscle
Genioglossal muscle
Sublingual artery
Mylohyoid muscle
Digastric muscle
(B)

Current/Competing Products

The current process:

- CT data
- Materialize Mimics and 3-Matic

Competing Products:

- Articulated bone reconstruction bar
- Modular mandibular prosthesis
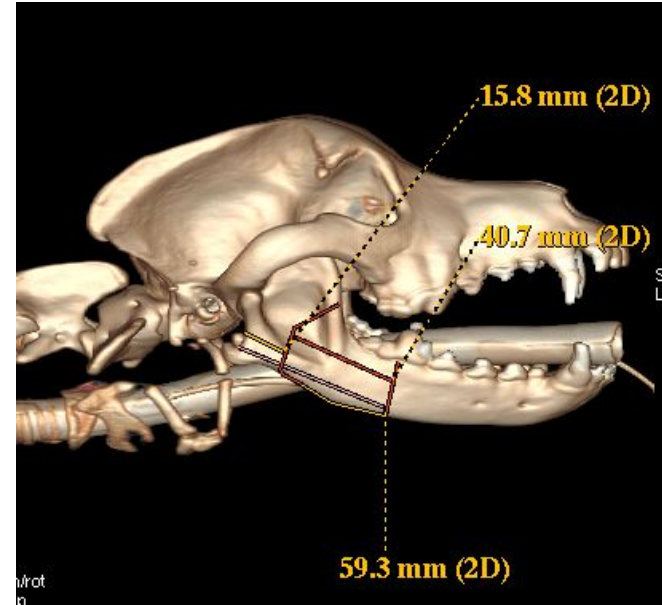- Mandibular prosthetic apparatus kit

Figure 7: Right lateral view of a three-dimensional reconstruction of a CT scan of the skull of a dog
https://www.eastcottreferrals.co.uk/article/205/Immediate-Mandibular-Bone-Reconstruction-Dog/

PDS-Summary

Function:
- Optimize dimensions of jaw implant
- Efficient placement of screws
- Avoid problem areas

Final Product:
- Easy to use for doctors and veterinarians
- Accurately represent dog anatomy
- Functional and aesthetic outcome

Cost:
- $500
- Subscriptions and licences to software

Figure 8: Veterinarian and Dog Patient
https://nadovet.com/services/pet-dental/pet-dental-faq.html
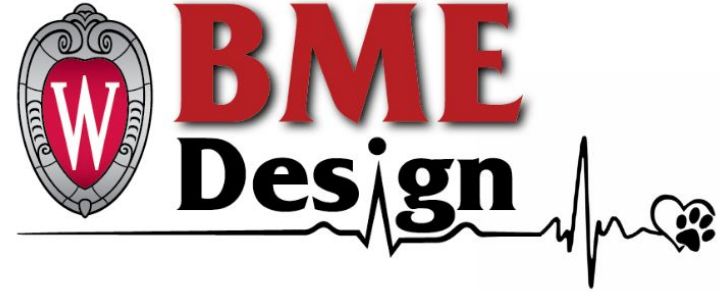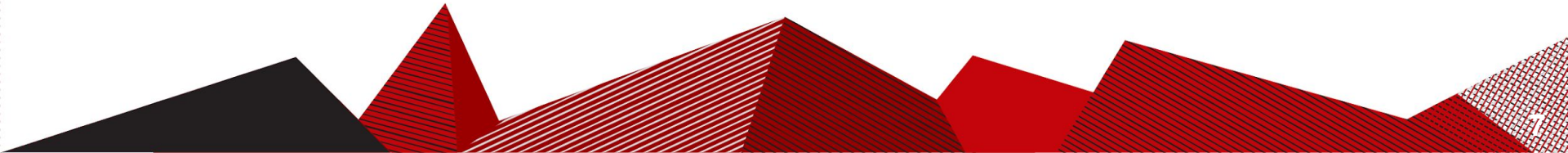
Design Ideas

Figure 9: Team Logo

- **The Tiered: Matlab / SolidWorks**
  - Process split between multiple programs

- **The Monolithic - Plug-In to Image-J (Java)**
  - Open source coding with easy interface

- **The Iterator- Generative Design**
  - Computer optimizes design over and over again

- **The Square One - Independent Application**
  - Generate a program from scratch

Design #1- The Tiered

MatLab and Solidworks

- Portions of the process are split between different programs
- Easiest to program
- Requires multiple licenses
- Requires switching between programs

Generate General Dimensions in MatLab

↓

Determine Screw Placement in MatLab
(User input or algorithm)

↓

Output 3D CAD Files

↓

Stress Test in SolidWorks

Stress Failure

↓

3D-Print Implants
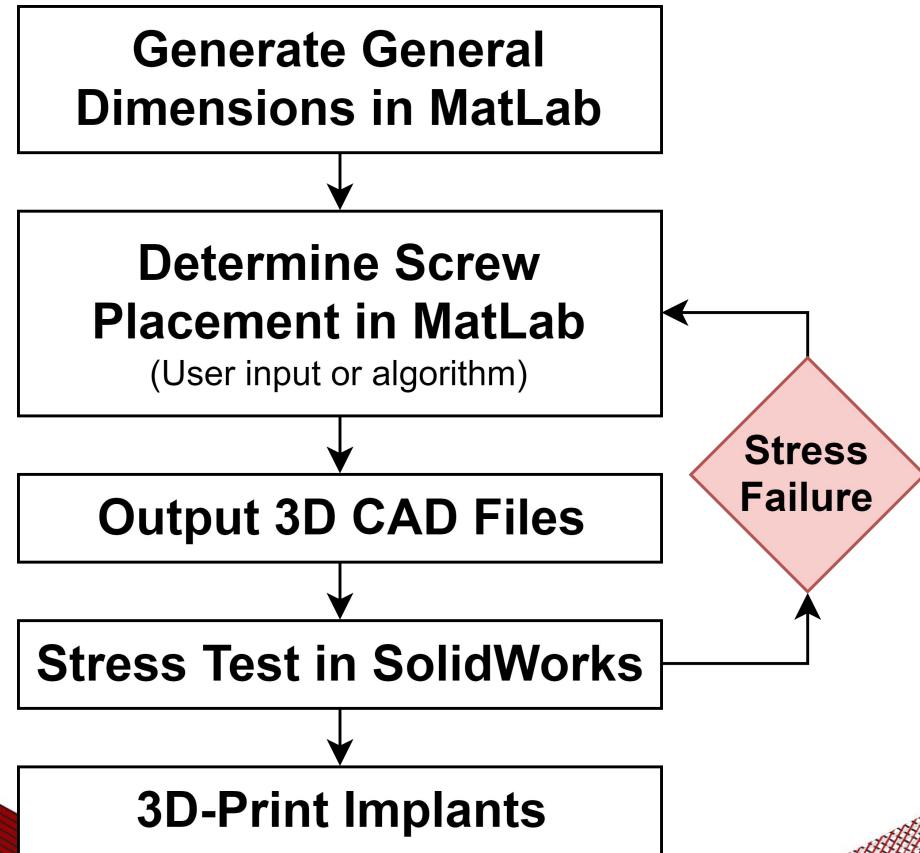
Figure 10: Tiered Design Flowchart

8

Design #2- The Monolithic
Java Plug-In ImageJ

- Easiest interface for user
- Open source base application
- Libraries of existing code
  [imagej.nih.gov/ij/plugins/]
- Common coding language

Activate Plug-In in Host Application

↓

Load 3D Patient Scan File

↓

User Selects Region for Resection

↓

Determine Screw Placement and Stress Test
(Use Pre-existing packages)

↓

Output 3D-Files and Print

Figure 11: Monolithic Design Flowchart

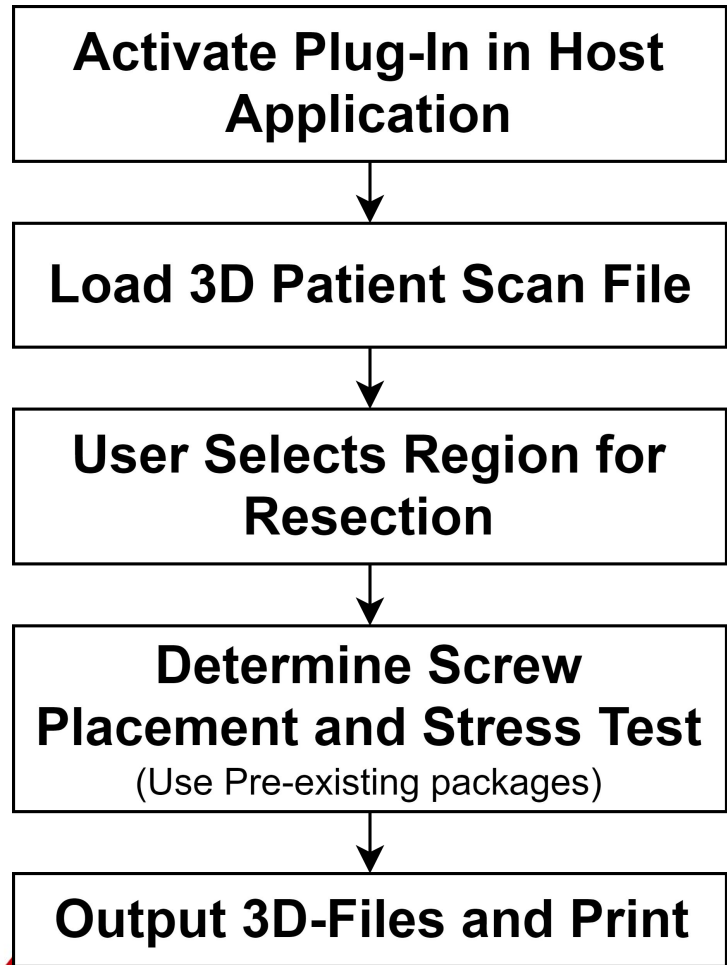# Design #3- The Iterator
Generative Design

- Computer generates and optimizes design thousands of times
- Based on machine learning
- Hard to build from scratch
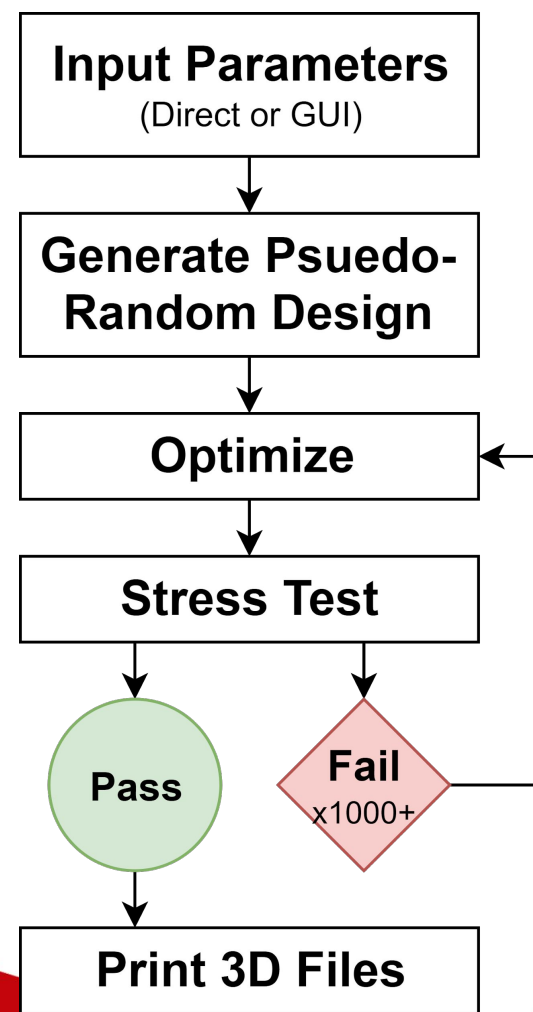- Many easy-to-use services exist [CGCookie]

Input Parameters
(Direct or GUI)

Generate Psuedo-Random Design

Optimize

Stress Test

Pass

Fail
x1000+

Print 3D Files

Figure 12: Iterator Design Flowchart

Design #4- The Square One

Independent Application

- Easy-to-use interface
- Similar to the ImageJ plug in
- Need to build everything from scratch
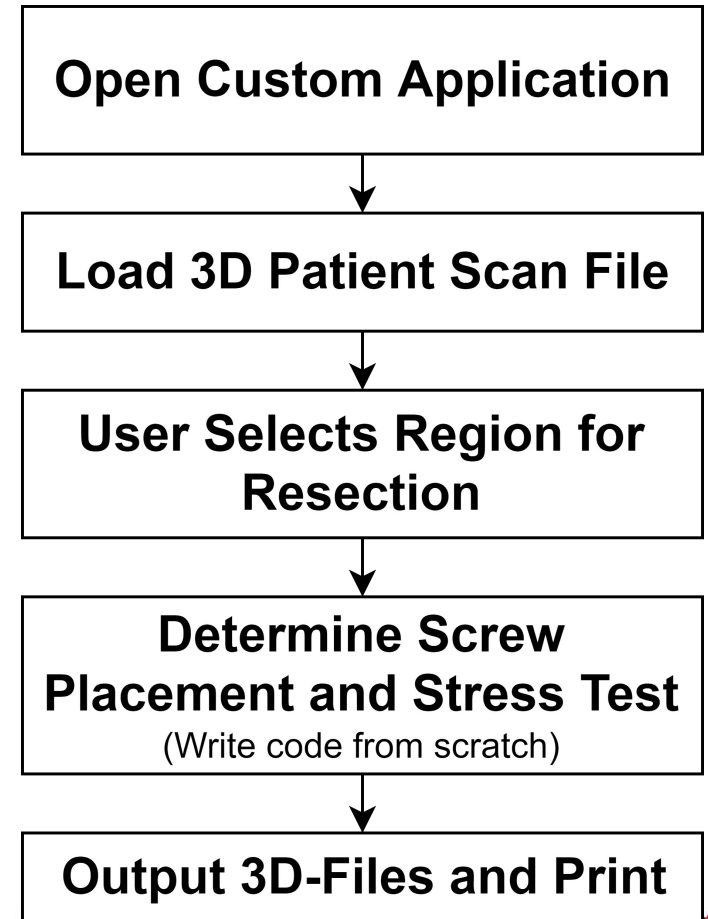- Small executable
- Prone to bugs

```
┌─────────────────────────────────┐
│   Open Custom Application        │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│   Load 3D Patient Scan File      │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│   User Selects Region for        │
│   Resection                      │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│   Determine Screw                │
│   Placement and Stress Test      │
│   (Write code from scratch)      │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│   Output 3D-Files and Print      │
└─────────────────────────────────┘
```

Figure 13: Square One Design Flowchart

Design Matrix

| Rank | Criteria | Weight | The Tiered | | The Monolithic | | The Iterator | | The Square One | |
| | | | Matlab / SolidWorks | | Plug-In to Image-J (Java) | | Generative Design | | Independent Application | |
			Score (10 max)	Weighted Score	Score (10 max)	Weighted Score	Score (10 max)	Weighted Score	Score (10 max)	Weighted Score
1	Cost	20	2	4	10	20	3	6	10	20
2	Accessibility / Compatibility	20	4	8	10	20	10	20	10	20
3	Convenience / Ease of Use	15	6	9	8	12	10	15	8	12
4	Computational / User Time	15	7	11	8	12	1	2	5	8
5	Ease of Programming	15	8	12	9	14	7	11	2	3
6	Resolution of Implant	10	7	7	7	7	10	10	7	7
8	Safety	5	10	5	10	5	10	5	10	5
	Sum	100	Sum	56	Sum	90	Sum	68	Sum	75

Figure 14: Design Matrix

Current Chosen Design
Java Plugin ImageJ

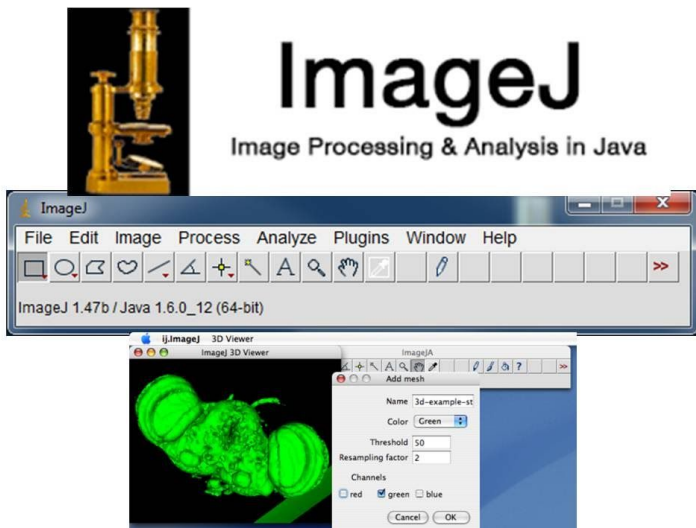**Figure 15:** ImageJ Logo and Set Up
https://i.ytimg.com/vi/2vHUbuGyoC0/maxresdefault.jpg

- Most cost effective
- Most compatible/ accessible
- Time efficient
- Easiest interface

Potential Problems

- File type compatibility [imagej.1557.x6.nabble.com/]
  - Plug-in development
- Difficulty of writing code
- No existing package to conduct finite element testing
- Simplified force analysis methods
  - Large factor of safety

Figure 16:
Image of printed implant
[From Client]

Conclusion and Future Work

- Development of The Monolithic using Java and ImageJ
- Run process with multiple variations
- 3D print initial prototype
- Consult with professionals
- Revise process

Figure 17: A puppy biting a finger in demonstration of the typical forces acting in the canine jaw
https://topdogtips.com/wp-content/uploads/2017/06/How-bite-force-in-dogs-is-measured.jpg

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- The BME Department, for providing us with the opportunity to work on this project

Figure 18:
Team Logo

References

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Kim, S., Arzi, B., Garcia, T. and Verstraete, F. (2018). Bite Forces and Their Measurement in Dogs and Cats. *Frontiers in Veterinary Science*, 5.

MathWorks - Pricing and Licensing: https://www.mathworks.com/pricing-licensing.html

SolidWorks - Pricing and Licensing: https://www.solidworks.com/how-to-buy

ImageJ Plug-Ins - https://imagej.nih.gov/ij/plugins/

CGCokkie.com - Generative Modeling and Design: https://cgcookie.com/course/generative-modeling-design-with-Midge-sinnaeve

Imagej.1557.x6.nabble.com - Convert ImageJ Stacked tiff to stl for 3D printing: http://imagej.1557.x6.nabble.com/Convert-Imagej-Stacked-tiff-to-stl-for-3D-Printing-td5002493.html

Competing Products - Manolidis, S. (1998). *Modular mandibular prosthesis*. US6060641A. [Accessed 18 Sep. 2019].

Questions?