1.5 Concept Generation

100 Concepts

1. Ring design with both internal and external fins
2. 3D printable
3. Polymers fiber material
4. Carbon fiber material
5. Titanium material
6. Titanium alloy material
7. Polyethylene material
8. Cobalt-chrome material
9. Locking mechanism
10. mm Onlay Design
11. 6 mm Inlay Design
12. 9 mm Onlay Design
13. 9 mm Inlay Design
14. 12 mm Onlay Design
15. 12 mm Inlay Design
16. Surface coating to increase bone in-growth
17. Design with force sensors
18. Biomimetic materials
19. Implement and electrical component to assist in mobility
20. Liquid component built within the implant for shock absorption
21. Design that can be adjusted to fit.
22. Design that can adjust with growth (pediatric design)
23. Design that promotes tissue regeneration.
24. Design that does not promote unwanted immune responses.
25. Design that promotes only wanted immune responses.
26. Implant customization
27. Surface of the implant seeded with EVs to promote healing.
28. Cement fixation
29. Screw fixation
30. Pin fixation
31. Release mechanism for medicine as implant deteriorates

Hollow Cylinder(s)

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32. Small diameter cylinder design with 2 external fins
33. Small diameter cylinder design with 3 external fins
34. Small diameter cylinder design with 4 external fins
35. Small diameter cylinder design with 5 external fins
36. Small diameter cylinder design with 6 external fins
37. Small diameter cylinder design with 2 internal fins
38. Small diameter cylinder design with 3 internal fins
39. Small diameter cylinder design with 4 internal fins
40. Small diameter cylinder design with 5 internal fins

41. Small diameter cylinder design with 6 internal fins
42. Small diameter cylinder design with no external or internal fins
43. Small diameter cylinder design with equal internal and external fin
44. Small diameter cylinder design with various internal and external fins
45. Large diameter cylinder design with no external or internal fins
46. Large diameter cylinder design with 2 external fins
47. Large diameter cylinder design with 3 external fins
48. Large diameter cylinder design with 4 external fins
49. Large diameter cylinder design with 5 external fins
50. Large diameter cylinder design with 6 external fins
51. Large diameter cylinder design with 2 internal fins
52. Large diameter cylinder design with 3 internal fins
53. Large diameter cylinder design with 4 internal fins
54. Large diameter cylinder design with 5 internal fins
55. Large diameter cylinder design with 6 internal fins
56. Large diameter cylinder design with no external or internal fins
57. Large diameter cylinder design with equal internal and external fin
58. Large diameter cylinder design with various internal and external fins
59. Large diameter cylinder design with no external or internal fins
60. Two-cylinder design with no fins
61. Two-cylinder design with external fins on inner cylinder
62. Two-cylinder design with internal fins on outer cylinder
63. Two-cylinder design with internal fins on outer cylinder and external fins on inner cylinder

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64. Solid small diameter cylinder design with no fins
65. Solid small diameter cylinder design with external fins
66. Solid large diameter cylinder design with no fins
67. Solid large diameter cylinder design with external fins
68. Two-cylinder design with solid inner cylinder with no fins
69. Two-cylinder design with solid inner cylinder with external fins
70. Vary cylinder length from fin length
71. 0.5 in cylinder/fin length
72. 1.0 in cylinder/fin length
73. 1.5 in cylinder/fin length
74. 2.0 in cylinder/fin length
75. 0.05 in fin thickness
76. 0.10 in fin thickness
77. 0.15 in fin thickness
78. 0.20 in fin thickness
79. 0.2 in fin width
80. 0.4 in fin width
81. 0.6 in fin width
82. 0.8 in fin width
83. 1.0 in fin width

Change cylinder geometry

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84. Hollow rectangular prism with no fins
85. Hollow rectangular prism with fins
86. Solid rectangular prism with no fins
87. Solid rectangular prism with fins
88. Hollow triangular prism with no fins
89. Hollow triangular prism with fins
90. Solid triangular prism with no fins
91. Solid triangular prism with fins
92. Square prism
93. Pentagonal prism
94. Hexagonal prism
95. Trapezoidal prism

}

Fin Geometry

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96. Rectangular fins
97. Triangular fins
98. Annular fins
99. Wedge fin
100. Perforated fins

}

3 High Fidelity Concepts

The high-fidelity concepts were chosen based on concepts that proved to be the most functional and accomplish the solution. Three of these concepts appeared to be the most promising.

Design Solution 1

This is based on Exactech's three fin design for the humeral anchor. This model uses Exactech’s already existing shape for the anchor. This model uses a shape that makes twisting the anchor possible. This design also allows for deformation and expansion to occur after implantation to lock the component in place. The wedge shape is implemented to prevent the component from levering out. This design produced the greatest resistance to the lever out force (Newtons) in the 2023 Exactech senior design project.

Design Solution 2

A new design for the implant utilizing a large cylinder with no fins instead of a smaller single cylinder and fins could help to better resist moments and forces. This idea could be modified in many ways by adding internal fin or moving the ring in towards the center and adding external fins.

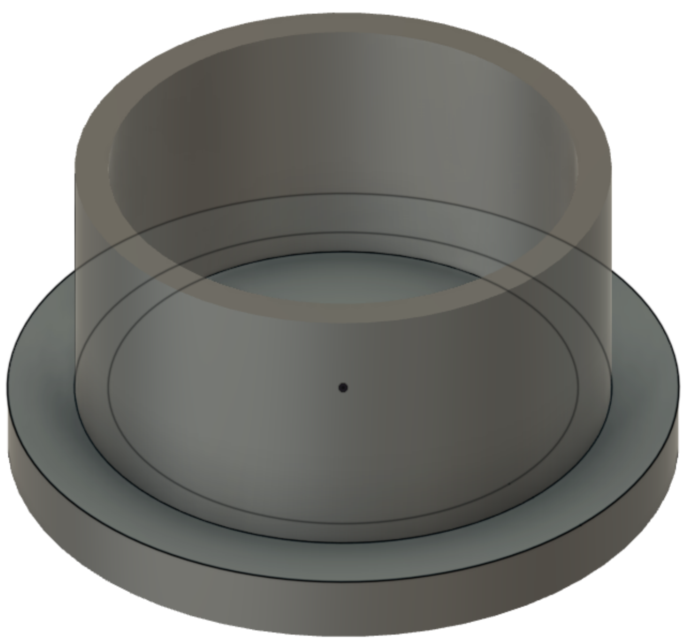

Figure 1: Implant Design idea utilizing a ring design.

Design Solution 3

Utilizing last year's design of a smaller cylinder with six external fins. This design should be able to resist torque and rocking moments. It is the best of the smaller cylinder designs, while also minimizing the required bone for successful implantation.

5 Medium Fidelity Concepts

The medium fidelity concepts were chosen based on concepts that proved to be lacking full functionality but closer to accomplishing the solution.

1. Large diameter hollow cylinder with internal fins
2. Large diameter hollow cylinder with smaller hollow internal cylinder
3. Small diameter hollow cylinder with four external fins
4. Small diameter hollow cylinder with five external fins
5. Small diameter hollow cylinder with internal fins and external fins

Concept Generation Tools

Several tools were used for developing design concepts. One tool that proved to be most useful was Anti-problem. Different design concepts were created that would increase the dislodgment and lifespan of the humeral anchor. Determining concepts that would prevent our design from meeting the requirements aided in discovering different attributes and factors that were causing the problem. Another tool that proved beneficial was Battle of Perspectives. The group was split and assigned one side to produce solutions that would ease manufacturing and the other side was assigned to produce solutions that would improve the lifespan. The concepts generated provided a guide in determining the important requirements of the design. Biomimicry was another tool used in determining a lot of concepts. The natural shape of the humerus along with its connection to the glenoid were studied to determine what aspect of it be beneficial to the design.

1.6 Concept Selection

1. Small diameter hollow cylinder with three external fins design
2. Large diameter hollow cylinder with no fins design
3. Small diameter hollow cylinder with six external fins design
4. Large diameter hollow cylinder with internal fins design
5. Large diameter hollow cylinder with smaller hollow internal cylinder and no fins design.

House of Quality

The house of quality table was generated to compare the sponsor's interpreted need statements against engineering characteristics. This was done to ensure that each of the needs was met. These needs were further analyzed to determine their order of importance. The top five engineering characteristics will continue to additional tables to compare our high and medium-fidelity concepts against. Please note that the engineering characteristics were modified from previous sections to better reflect what should be gauged and what can be tested.

		Engineering Characteristics							
Units		m^3	N*m	MPa	N*m	Time, Steps	cycles	Time	$
Improvement Direction		v	^	^	^	v	^	v	v
Customer Requirements	Importance Weight Factor	Overall Volume	Torque	Shear	Rocking Moment	Quick/Simple Install	Fatigue	Easy To Manufacture	Cost
Strengthen Interface	6	1	1	3	9				
10 Year Lifespan	5		1	1	9		9		
Size Constraints	1	3							
Easier To Implant	3					3			
3D Printable	3	1						5	1
Raw Score (217)		12	11	23	99	9	45	15	3
Relative Weight %		5.5	5.1	10.6	45.6	4.1	20.7	6.9	1.4
Rank Order		5	6	3	1	6	2	4	7

1	2	3	4	5
Rocking Moment	Fatigue	Shear	Easy to Manufacture	Overall Volume

Pugh Charts

The Pugh chart focused on taking the engineering characteristics and comparing them against the medium and high-fidelity concepts generated in the concept generation stage. This is done to determine the order in which the concepts will be generated and tested in later stages. Through the Pugh chart the three main concepts were selected. Concept 2 Large diameter cylinder with no fins, Concept 3 small cylinder with six external fins, and Concept 5 large diameter cylinder with small hollow internal cylinder and no fins.

		Concepts				
Selection Criteria	Equinoxe	1	2	3	4	5
Overall Volume	Datum	S	+	-	-	-
Torque		S	+	+	+	+
Shear		S	+	+	+	+
Rocking Moment		S	-	+	+	+
Quick/Simple Install		+	-	+	-	-
Fatigue		S	-	+	+	+
Easy To Manufacture		+	-	-	-	-
Cost		+	+	-	-	+
# Pluses		3	4	5	4	5
# Minuses		0	4	3	4	3

		Concepts		
Selection Criteria	4	2	3	5
Overall Volume	Datum	+	+	+
Torque		-	+	+
Shear		-	-	+
Rocking Moment		-	-	+
Quick/Simple Install		+	-	-
Fatigue		+	-	+
Easy To Manufacture		+	+	+
Cost		+	+	+
# Pluses		5	4	7
# Minuses		3	4	1

AHP

The AHP (Analytical Hierarchy Process) is used to compare the final three concepts determined in the Pugh chart against the main five engineering characteristics determined in the house of quality. This mathematical process is used to prevent biases from arising in the decision-making process. The result shows that there is minimal bias. (Consistency Ratio < 0.1)

Critera Comparison Matrix [C]						
Critera	Overall Volume	Torque	Shear	Rocking Moment	Quick/Simple Install	Fatigue
Overall Volume	1	7	3	3	1/3	3
Torque	1/7	1	1/3	1/3	1/7	3
Shear	1/3	3	1	1/3	1/3	3
Rocking Moment	1/3	3	3	1	1/3	3
Quick/Simple Install	3	7	3	3	1	7
Fatigue	1/3	1/3	1/3	1/3	1/7	1
Sum	5.14	21.33	10.67	8.00	2.29	20.00

Normalized Critera Comparison Matrix [NormC]							
Criteria	Overall Volume	Torque	Shear	Rocking Moment	Quick/Simple Install	Fatigue	Criteria Weights
Overall Volume	0.19	0.33	0.28	0.38	0.15	0.15	0.25
Torque	0.03	0.05	0.03	0.04	0.06	0.15	0.06
Shear	0.06	0.14	0.09	0.04	0.15	0.15	0.11
Rocking Moment	0.06	0.14	0.28	0.13	0.15	0.15	0.15
Quick/Simple Install	0.58	0.33	0.28	0.38	0.44	0.35	0.39
Fatigue	0.06	0.02	0.03	0.04	0.06	0.05	0.04
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Consistency Check		
Weighted Sum Vector {Ws}	Criteria Weights {W}	Consistency Vector
1.70	0.25	6.92
0.37	0.06	6.16
0.68	0.11	6.43
1.00	0.15	6.58
2.63	0.39	6.71
0.29	0.04	6.50
Lambda	6.55	
RI Value	1.25	
Consistency Index	0.11	
Consistency Ratio	0.09	

Final Selection

The final concept selection utilizes the previous AHP to determine a final concept that will be this project's focus. Concept 3 was chosen which is the small diameter hollow cylinder with six external fins design. This concept is a continuation from the previous year's concept generation stage. It was not determined to be the best, but this is due to an error in testing.

Concept	Alternative Value	Rank
2	0.30	3
3	0.40	1
5	0.31	2