Topology optimization process for new designs of reconstruction plates used for bridging large mandibular defects

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Abstract

Loss of bone in the mandible as a result from for example resection of bone tumors or trauma, can in more complex cases be reconstructed using a reconstruction plate to provide stability between the remaining mandible stumps. Different studies on reconstruction plates present a fracture rate of 2.8-9.8%. The rate of plate fracture and plate loosening increases the need to improve the design of the reconstruction plate. A useful tool to find new designs for structures is topology optimization. Topology optimization is a mathematical based method where it is possible to define an optimization problem for a specific load case. Based on the defined problem, the solver calculates the most appropriate design to reach the final goal. The aim of this work is to investigate, describe, and discuss how new designs for reconstruction plates used for bridging large mandibular defects can be achieved by using topology optimization as a tool.

Two software programs handling topology optimization from Altair Engineering were used: SimLab 14.0 and HyperMesh 14.0. Both of them uses the solver OptiStruct to solve the defined topology optimization problem. The topology optimization problem was defined to minimize the compliance of the structure with an upper limit of the allowed volume fraction used for the new design. Three different clenching tasks were examined: right unilateral clench, clenching in the intercuspal position, and incisal clench. All three load cases resulted in different designs, the designs were also affected by the initial amount of screws used, and by the defined value on the allowed thickness of the created parts in the new design. The results gave an initial understanding of topology optimization, and indicated the possibilities a design process with topology optimization has to achieve new designs for reconstruction plates used for large mandibular fractures.
Interpretation of the result

Figure 17. In the uppermost picture the contour plot is applied and all elements in the plate are visible. In the three lower pictures the iso-surface plot are applied with different threshold values: elements with a density above 0.2, 0.3, respective 0.5 are visible. Simulation with the RUC load case, with a volume fraction of 0.2 and a minimum thickness of 6 mm.
Upper limit on the volume fraction

Figure 21. Simulations with different values (0.2, 0.3, 0.4, 0.5) applied for the upper limit of the volume fraction for the load case RUC, with a threshold value of 0.3.
Minimum member size

Figure 24. Simulations with different values of the allowed minimum thickness (3, 4, 5, 6, 7 mm) for the design with a volume fraction of 0.2 for the load case RUC. Threshold value 0.3.
Figure 25. Simulations with different values of the allowed minimum thickness (3, 4, 5, 6 mm) for the design with a volume fraction of 0.3 for the load case CICP. Threshold value 0.6.
Figure 26. Similarities in the design when a volume fraction of 0.3 and minimum thickness of 6 mm is used respective a volume fraction of 0.2 and minimum thickness of 5 mm is used as the defined parameters for the RUC load case. Meanwhile the smaller part in the picture to the right is neglected. Threshold value 0.3.
Figure 27. Different amount of screws used for the load case RUC: 7 on the right side and 4 on the left side, 4 on both sides, respective 3 on both sides. A volume fraction of 0.2 with a minimum thickness of 3 mm is used. Threshold values: 0.3, 0.3, respective 0.1.
Figure 28. Different amount of screws used for the load case CICP: 4 respective 3 on both sides. A volume fraction of 0.2 with a minimum thickness of 3 mm is used. Threshold value 0.6.
Decreasing muscular forces

Figure 29. The right side muscles scaled to 90% respective 40% of the initial muscle force, respective the muscle forces on both sides scaled to 40% of the initial muscle force for the load case CICP. A volume fraction of 0.2 and a minimum thickness of 3 mm is used with four screws on each side. Threshold value 0.6.
Comparison of different load cases

Figure 30. The three different load cases RUC, CICP, respective IC, with a volume fraction of 0.2 and a minimum thickness of 3 respective 6 mm. Threshold value 0.3 for RUC, 0.6 for CICP, and 0.3 respective 0.5 for IC. All screws are used in the simulations.
Figure 31. Simulations for the two load cases CICP and IC with four screws on both sides, the upper limit on the volume fraction is set to 0.2 and a minimum thickness of 3 mm is used.
Weighted compliance

Figure 32. Weighted compliance for the load case RUC, CICP, and IC with a volume fraction of 0.2 and a minimum thickness of 3 mm. In the left case has weighting factor 1 been used for all three load cases, and in the right case has weighting factor 1, 4.5, and 1.6 been used for respective load case to gain similar compliance for each load case. Four screws on both sides of the plate has been used. Threshold value of 0.3, respective 0.4.