Evaluation of the feasibility of 3D-printed Ti-6Al-4V assembled bone plates

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Abstract

1. **Introduction**

Patient specific guides and bone plates for the correction of antebrachial angular limb deformities significantly improve the accuracy of the surgery, reduce operating time and accelerate recovery(1)(2). These personalised solutions are mainly produced using additive manufacturing (AM) methods due to the freedom of geometric complexity. However, their high cost, due to significant design preparation and production expenses, limits their use in clinical practice(3).

To optimize the preparation process, we propose to combine these solutions with a newly modular system, usable both as surgical guide and for stabilisation during bone healing. This new system is made of two patient-specific plates and an additional assembly device (realised with two clips), which joins the plates and realigns bone fragments. However, compared to a monobloc plate, the assembly system reduces the bending properties4 and potentially alters the implant fatigue life, which is a critical factor, as the most common mode of implant failure is due to cyclic fatigue 5. Over a 3-month healing period on average, authors consider that a dog loads its implant between 100.000 and 250.000 cycles(5)(6).

The aim of this study was to evaluate the mechanical performance of this new modular system under both static and cyclic loading conditions, thereby providing insights into its potential applications in clinical settings. As the fatigue properties of AM bone plates are known to be lower than those of conventional method (CM) bone plates(7), the study will compare both manufacturing methods

2. **Method**

2.1 Modular system definition and fabrication

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Modular systems were compared to reference monobloc plates (without assembly system). Both have identical dimensions (100x10x3.5 mm3), with the only distinction being the assembly mechanism in the modular plates. All reference plates and modular systems were produced with Ti-6Al-4V ELI using either CM or AM. CM parts were internally milled with a Haas OM2 machine (FEMTO-ST). AM parts were printed using selective laser melting (SLM) process on SLM®500 and had a post heat treatment (2h at 800∘C under Argon).

2.2 Mechanical testing

Mechanical testing consisted of quasi-static and cyclic fatigue four points bending tests using an electrodynamic machine (ElectroPuls E1000) and following the standard ASTM F382-17(8). The maximal deflection was recorded using an optic sensor (Opto NCDT). The maximal deflection was recorded using an optic sensor (Opto NCDT). The quasi-static tests were performed on 6 samples of each group at a rate of 0.1mm/s to 10mm of maximal deflection. The bending properties were computed following the ASTM F382-17. The cyclic tests were performed on 1 CM sample and 4 AM samples of each group at 25% of the maximal load before plastic domain (cycles: 30.5-305N at 5Hz). Each test was conducted to reach 1 million cycles: the number of cycles was recorded at failure if it occurs before the end of the fatigue test. Fretting wear and fracture were observed using x-ray tomography and numerical microscope.

3. Results and discussion

All AM reference plates failed before reaching 10mm of deflection, unlike of the CM reference plates. However, their mean static bending properties are close, with less than 5% of difference, which contrasts with findings from other studies regarding strengh(5)(7)(9):

- Stiffness: 342±4N/mm (CM) and 327±3N/mm (AM)

- Strength: 1215±13N (CM) and 1225±17N (AM)

Modular systems have a lower bending stiffness and strength in comparison with reference plates for both fabrications methods, which could be beneficial for the stress shielding effect (4). Their mean bending properties show some differences:

- Stiffness: 227±5N/mm (CM) and 204±2N/mm (AM)

- Strength: 991±154N (CM) and 1012±88N (AM)

The cyclic tests show better fatigue performance for CM than AM parts. All CM samples (reference plates and modular systems) have reached 1M (i.e. 1.000.000) cycles. The results for AM process differ:

- Reference plates: Two samples reached 1M and two samples fractured before 200.000 cycles

- Modular systems: One sample reached 400.000 cycles with fracture outside of the assembly system while three samples fractured around 800.000 cycles with breaks within the assembly system.

This suggests that, prior to assembly system, the inherent porosity and surface roughness of AM parts have the most significant impact on their cyclic life. Although AM cyclic tests revealed variability, modular systems using AM could survive 250.000 cycles without failure.

Therefore, the use of AM assembled bone plate seems feasible, especially considering that surface post-treatments that was done can significantly improve the cyclic life(7). Additional samples will undergo fatigue testing to perform a statistical analysis. Further biomechanical testing is required to confirm the suitability of this modular system for clinical use.

References:

1. Carwardine DR, Gosling MJ, Burton NJ, O'Malley FL, Parsons KJ. Three-Dimensional-Printed Patient-Specific Osteotomy Guides, Repositioning Guides and Titanium Plates for Acute Correction of Antebrachial Limb Deformities in Dogs. *Vet Comp Orthop Traumatol.* 2021;34(1):43-52. doi:10.1055/s-0040-1709702

2. Worth AJ, Crosse KR, Kersley A. Computer-Assisted Surgery Using 3D Printed Saw Guides for Acute Correction of Antebrachial Angular Limb Deformities in Dogs. *Vet Comp Orthop Traumatol.* 2019;32(3):241-249. doi:10.1055/s-0039-1678701

3. Teo AQA, Ng DQK, Lee P, O'neill GK. Point-of-Care 3D Printing: A Feasibility Study of Using 3D Printing for Orthopaedic Trauma. *Injury.* 2021;52(11):3286-3292. doi:10.1016/j.injury.2021.02.041

4. Subasi O, Oral A, Noyan S, Tuncozgur O, Lazoglu I. In silico analysis of modular bone plates. *Journal of the Mechanical Behavior of Biomedical Materials.* 2021;124:104847. doi:10.1016/j.jmbbm.2021.104847

5. Polak S, Beever L, Wade A, Fukuoka M, Worth A. Biomechanical comparison of titanium alloy additively manufactured and conventionally manufactured plate-screw constructs. *New Zealand Veterinary Journal.* 2024;72(1):17-27. doi:10.1080/00480169.2023.2264805

6. Goin B, Buttin P, Lafon Y, Massenzio M, Viguier E, Cachon T. Biomechanical cyclic loading test of a synthetic ligament fixation system used for intra-articular stabilization of deficient canine stifles. *Open Veterinary Journal.* 2022;12(3):341-350. doi:10.5455/OVJ.2022.v12.i3.6

7. Lee HR, Adam GO, Kim SJ. Application of Patient-Specific Instrumentation in a Dog Model with Antebrachial Growth Deformity Using a 3-D Phantom Bone Model. *Veterinary Sciences.* 2022;9(4):157. doi:10.3390/vetsci9040157

8. ASTM F382-17. Standard Specification and Test Method for Metallic Bone Plates.

9. Gupta SK, Shahidsha N, Bahl S, et al. Enhanced biomechanical performance of additively manufactured Ti-6Al-4V bone plates. *Journal of the Mechanical Behavior of Biomedical Materials.* 2021;119:104552. doi:10.1016/j.jmbbm.2021.104552