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Mechanical investigation of assembled osteosynthesis plates: experimental and numerical approaches

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1. Introduction

Osteosynthesis plates are widely used in veterinary orthopaedic surgery (Lee et al, 2022). However, bone plates are usually not suitable for all clinical cases due to species variability in terms of sizes and geometries. To facilitate surgical accessibility and adapt the length according to the clinical case our approach proposes assembled plates system. It consists of two short plates that are separately fixed on each side of bone fragments with an assembly system to join them. Some patents of such system have already been published (ex: Destainville et al, 2019), however, none of them is currently on the market.

The assembly system is the critical part that mostly determines the mechanical behaviour, yet no study except one numerical static study (Subasi et al. 2021) has investigated their mechanical properties. To ensure adequate performances before extensive use, numerical results need to be validated with experiments including fatigue behavior investigation.

However, comparing mechanical performances of bone plates based on published information is difficult. As discussed in publications: "the biomechanical literature for bone plates is diverse, inconsistent and heterogeneous" (Schorler et al. 2017). The aim of this study was to propose a reliable approach to evaluate the mechanical performance in comparison with existing plates, using both experiments and simulations.

2. Methods

2.1 Reference plate and protype definition

A reference bone plate ($10*150*3{,}5\,mm^3$ and 3,5 mm for the holes) for which geometry corresponds to that of commercial plates has been designed to mimic osteosynthesis plates used for large dogs. The prototype based on assembled plates has identical dimensions to the reference plate (figure 1). The references plates and the prototypes were made in 316L steel.

2.2 Finite element (FE) models

FE models of the reference plate and the prototype were designed and their performance compared by simulating 4 points bending tests in linear static analysis (SolidWorks Simulation v.2023), following the ASTM F382 standard (ASTM F382-17, 2017). Distance h between support rollers was 40 mm and distance a between loading rollers was 50 mm (figure 1). Contact and bold connectors with preload (0,5 Nm) and friction coefficient (0,2) were defined. A force of 40 N was applied on each upper loading roller. The final mesh (28577 tetrahedral elements) was defined after a convergence study (1% of error on displacement).

2.3 Verification and calibration of the FE models

Tensile test samples were extracted from the material plate to calibrate the material properties for the FE model (Young Modulus, Poisson ratio). The reference plates and the prototypes were machined with a HASS

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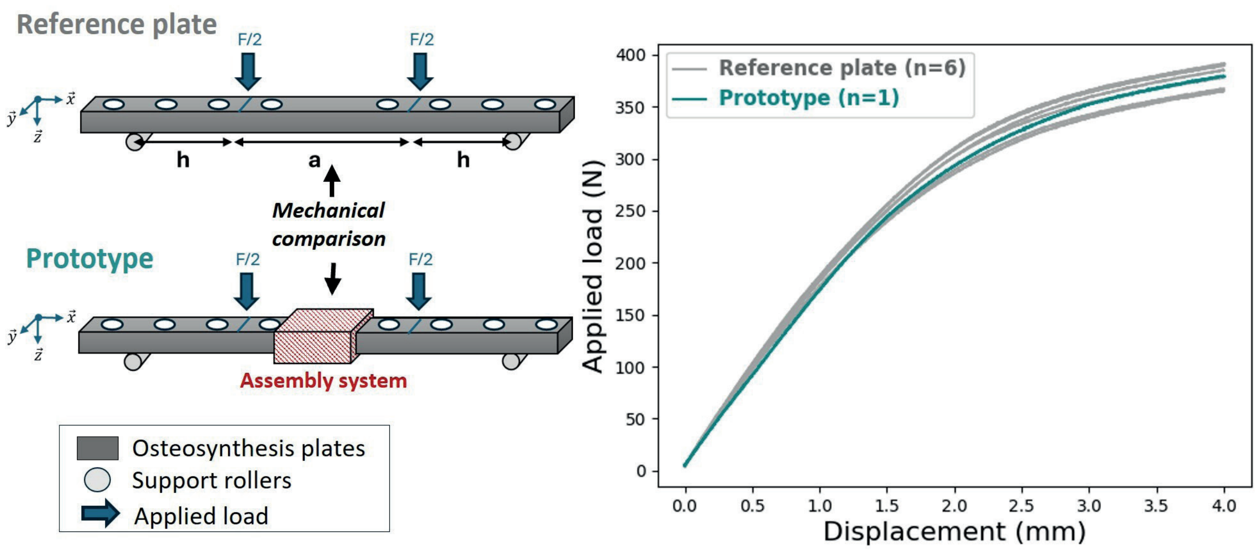

Figure 1. Mechanical comparison of the reference plate and the prototype.

Credit: L. Revol

OM2 milling machine. They were physically tested in static loading following the ASTM F382, as for the simulation. The bending stiffness (BS) was extracted from both the experiments and the simulations to evaluate the FE model. BS (N/mm) was defined as the slope of the linear region of the force - displacement curve.

2.4 Design improvement using FE simulations

The prototype geometry was then numerically modified using design of experiments to minimize the difference regarding the BS and the maximal Von Mises stress between the reference and the prototype. The maximal Von Mises stress was also checked to stay below the Yield stress defined by the Wöhler relationship to consider fatigue (200 MPa).

2.5 Experiments

The reference plates (n=6) and the retained prototype (n=1) were finally tested using electrodynamic system (ElectroPuls E1000) following the ASTM F382, both in static and cyclic loading. Displacement was recorded with a laser sensor (optoNCDT). The maximum cyclic load was defined according to the percentage of the reference plate proof load: 200N with R-ratio of 0,1 for 1 million cycles. The proof load corresponds of the load reached at 0.2% of the offset displacement (ASTM method). The number of cycles before failure was recorded.

3. Results and discussion

The challenge was to obtain appropriate stiffness and ensuring satisfactory cyclic life during bone healing. Figure 1 displays the force-displacement curves for the prototype and the reference plates, while Table 1 reports the preliminary mechanical criteria. The difference on BS between experimental and numerical is less than 10%. Static tests indicate that the retained prototype provides a slightly lower bending elastic stiffness in comparison to the reference plate, but a larger proof load. Reducing the BS could be benefit, because it could also help to reduce the "stress shielding" effect (Frost, 1994).

Cyclic tests enable to confirm the fatigue performance of the prototype which succeeds in reaching the reference's cycles to failure.

Table 1. Results from static and cyclic loadings.

Performance criteria	Reference plate (n=6)	Prototype (n=1)
Numerical BS. (N/mm)	192	186
Experimental BS (N/mm)	190 ± 5,2†	173
Proof load (N)	200 ± 4†	235
Cycles to failure	1 E 6	1 E 6

† means ± standard deviation

Credit: L. Revol

These preliminary results have to be evaluated and confirmed on a larger set of physical devices for different sizes. Moreover, only bending performances have been explored, while osteosynthesis plates have to respect torsion behaviour, for which no standard is defined (Schorler et al. 2017). Finally, the entire fixation system (i.e. the plate fixed to the bone by screws) needs to be assessed.

4. Conclusions

The study presents a method for evaluating the mechanical properties of assembled osteosynthesis plates, using a combination of simulation and experimentation, to achieve performance equivalent to that of reference plates. The encouraging preliminary results need to be confirmed by further tests.

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Conflict of Interest Statement

ennoia has no financial interest related to the results of this study.

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