Can implants move in bone? A longitudinal in-vivo micro CT analysis of implants under constant forces in rat vertebrae

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Objective(s):

Stationary stability of implants has been postulated. Despite, clinical observations suggested that constant loading may induce *implant migration*[1,2]. Interestingly, displaced implants did not become loose. If this phenomenon really exists remains puzzling.

In-vivo microcomputed tomography (µCT) allows to scan small animals at different time points at very high resolution. Hence, this method allows to quantify implant displacement over time and to assess the associated bone remodelling.

The aims of the present investigation were to asses (i) if implants can move in bone while remaining osseointegrated, and (ii) to assess the association between positional changes and the magnitude of applied force.

Materials & Methods:

Surgeries: Two customized machined implants (0.8 x 3.0 mm, Ra=0.8) were placed in the dorsal portion of caudal vertebrae of n=61 rats. The implants were exposed to constant forces (low force: 0.5 Newton, medium force: 1.0 N, high force: 1.5 N, original assignment: 16 animals/group) applied through a flat nickel titanium tension spring, or no forces (control/passive spring).

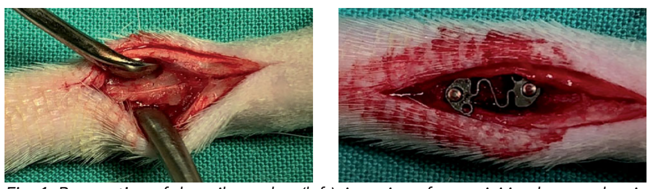

Fig. 1: Preparation of the tail vertebra (left), insertion of two mini-implants and a nickel titanium spring (right)

Scanning: In-vivo µCT *scans* were performed at 0, 1, 2, (all animals) and at 4, 6, and 8 weeks (31 animals). Threshold based segmentation was performed, and forthcoming scans were registered with previous scans based on the segmented bone tissue (Amira software). Implant migration was measured as the linear distance between corresponding implant tips.

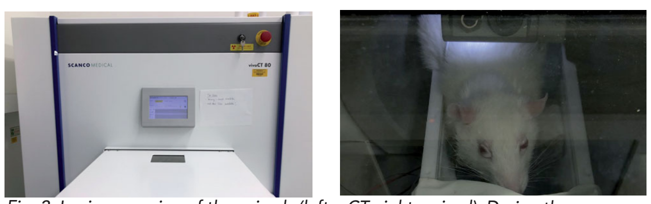

Fig. 2: In-vivo scanning of the animals (left: µCT, right: animal). During the scans, temperature and ECG of the animals were monitored.

Statistics: Linear mixed effects models were calculated to assess the relationship between implant displacement, applied force and time point. Error plots were created for descriptive purposes.

Results:

The post-operative healing was considered as generally uneventful. No complications such as allergic reactions, abscesses or infections were noted except for one animal, that repeatedly manipulated the wound. Metal and motion artifacts affected scans from eight animals, so missing values were interpolated. For all other scan, image registration was performed succesfully. Repetition of distance measurements at the anterior implant after one months revealed high reliability (ICC: 0.982).

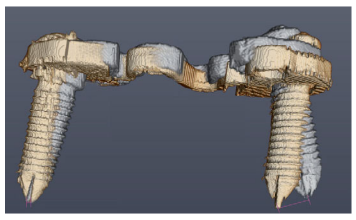

Fig. 3: Distance measurement at the tip of an implant showing extreme movement between week 0 (silver) and week 1 (gold).

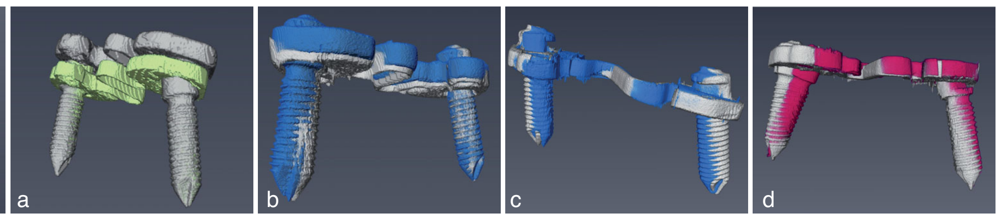

Fig. 4: Implant displacements between consecutive measurements in the (a) control group (week 0-2), (b) 0.5 N (week 0 to 1), (c) 1.0 N (week 6 to 8) and (d) 1.5 N (week 0 to 8) groups. The implant at the first time point is displayed in silver, the forthcoming scans have different colors. Displacements often continued in 1.0 N and 1.5 N groups until the end of the study.

Implant migration was more pronounced in the 1.0 N and 1.5 N compared to 0.5 N and control groups. Displacement of the posterior implant was in general greater compared to the anterior implant. In the 1.0 N and 1.5 N groups, tipping occured around a center of rotation at about one half to one third above the implant tip. In the 0.5 N group, the center of rotation was more cervical and the implant neck remained stable.

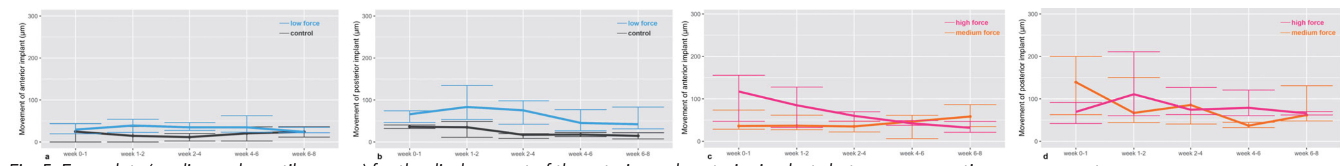

Fig. 5: Error plots (median and quartile ranges) for the displacement of the anterior and posterior implants between consecutive measurements. Notation: control = 0.0 N, low force = 0.5 N, medium force: 1.0 N, high force: 1.5 N.

The linear mixed effects models revealed significant association between implant movement and applied force (anterior: X^2=12.12, Df=3, p = 0.007, posterior: X^2=20.35, Df=3, p < 0.001) with an estimated between measurement movement of 12.94 / 51.72 µm, 43.42 / 81.82 µm, and 56.56 / 84.24 µm, respectively. The likelihood analyses also revealed a signficant decrease of movement velocity over time (anterior: X^2=20.35, Df=3, p < 0.001, posterior: X^2=6.17, Df=4, p=0.047). Implant movement was in most of the cases accompanied by new bone formation (Fig. 6), only two of 61 animals (high loading) exhibited circular defects.

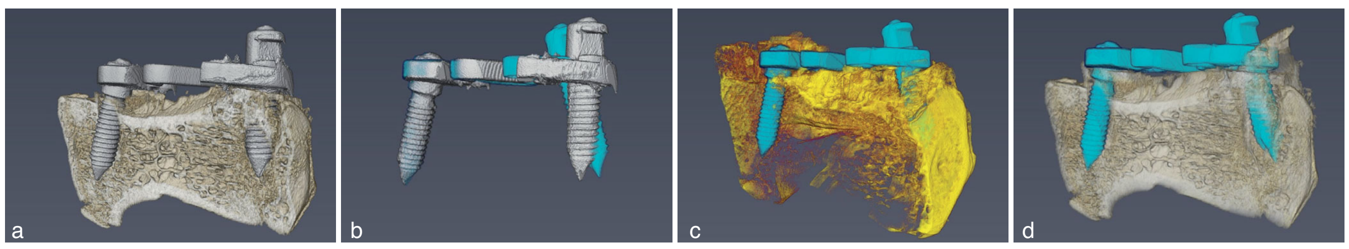

Fig. 6: New bone was formed despite of the implant movement (force: 1.5 N). (a) Implants and bone at week 1, (b) implant movement between week 1 and 8, (c) new bone formation from week 1 to 8, (d) osseointegrated implants at week 8.

Discussion:

The present study confirmed that implants can move in bone as a consequence to constant forces.

- Higher forces of 1.0 to 1.5 N induced distinct movements, accompanied by new bone formation.
- In the lower forces (0.5 N) groups implant movement decreased over time.
- Minor implant movements in the initial healing phase seemed to be associated with a regular healing process (control group).
- Implant displacement was in general accompanied by new bone formation. New bone formation at the former implant position may result from a callus distraction like process and a prolonged granulation phase.
- The customized nickel-titanium springs enabled constant loading during the experimental phase.
- The animal model has been sparseley used in dentistry. It was introduced by Renaud et al.[3,4]. It provides easy operative accessability and enables high resolution *in-vivo* µCT images.
- Future studies are needed to assess the immunological response, and the impact of surface roughness, and also the impact of immediate versus delayed loading protocols.

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