MEASURING *IN VIVO* STIFFNESS OF THE BONE-IMPLANT INTERFACE AS AN INDICATOR OF HEALING

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INTRODUCTION Orthopaedic and dental implants often fail if they are not properly stabilized during early healing. We've hypothesized that: 1) strain levels associated with implant micromotion influence early interfacial healing; and 2) *in vivo* stiffness of the interface can be non-invasively measured to assess the status of the interfacial healing.

In examining topic 2) above, we've examined healing at: 1) a *bone-implant-gap interface* ("BIGI"), with no initial contact between implant and bone; and 2) a *direct-bone-implant interface* ("DBII"), having regions of initial bone-implant contact as well as gaps. Here we report *in vivo* data on stiffness of bone-implant interfaces around a) pins and screws in BIGI, plus b) screws in DBII.

METHODS, cont'd In five groups of mice (Table 1, n = 5 in Groups II-V, n = 6 in Group I), we used 0.5 mm Ø pin or screw implants (Fig. 2) in different initial interfaces, BIGI vs. DBII.

Table 1: Experimental Groups

I	Pin	BIGI	150 µm motion, 60 cycles/day @ 1Hz, 7 days
II	Pin	BIGI	300 µm motion, 60 cycles/day @ 1Hz, 7 days
III	Screw	BIGI	150 µm motion, 60 cycles/day @ 1Hz, 7 days
IV	Screw	DBII	150 µm motion, 60 cycles/day @ 1Hz, 7 days
V	Screw	DBII	1.38 N load control, 60 cyc/day @ 1Hz, 7 days

RESULTS, cont'd Interfacial stiffness, k_i, showed the same trend as net stiffness k_{net}; mean values of k_i at days 1 vs. 7 increased ($p<0.05$) in Groups I-III but not in Groups IV and V (Fig 5).

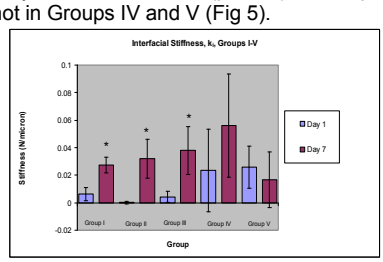

Fig 5: Mean ± 95% confidence for interfacial stiffness, k_i (* indicates different compared to day 1 data, p< 0.05)

MATERIALS AND METHODS Our mouse model used a motion device (Fig. 1) enabling stabilization, stroke-control, or load-control of test implants in mouse tibiae. A cap (not shown) covered the motion device to protect the implant from accidental loading or displacement between loading sessions, but allowed connection to a test system comprised of a load cell in series with a LVDT. Net stiffness, k_{net}, was defined as force on the implant (N) divided by implant displacement (µm) relative to the bone. *In vitro* and *in vivo* stiffness values were computed from raw data using techniques developed in the CATS. (Ongoing work has also automated the stiffness measurement and adapted it for dental implants used in humans.)

In BIGI cases (I-III), the 0.5 mm Ø implant was placed in 0.8 mm Ø hole; in DBII cases (IV-V), a 0.5 mm Ø screw was fit into a 0.40 mm Ø tapped hole. Groups I-IV had stroke-control to 150 or 300 µm, while Group V had load-control to the same force used in the 150 µm stroke control experiments of groups I and III. For each 60-sec loading session, we computed average values of k_{net} using a Matlab program. In the motion device (Fig. 1), the rubber O-ring with known stiffness k_w acted as a spring in parallel with the bone-implant interface, which was assumed to be as a spring with stiffness k_i . Thus, net stiffness measured *in vivo* was $k_{net} = k_w + k_i$, and interfacial stiffness was therefore $k_i = k_{net} - k_w$.

DISCUSSION A tripling of k_i over 7 days with pins and screws in BIGI is explained by bone healing in the interface. The mean k_i for Groups I-III at 7 d (0.032 N/µm) was approximately equal to the mean k_i for Groups IV-V over days 1 to 7 (0.030 N/µm), which had interfacial bone initially as well as 7 days later.

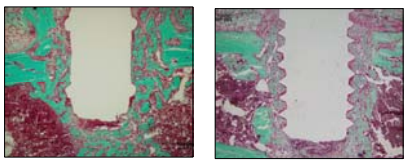

Fig. 6: 7-day interfaces of pin (L) and screw (R) implants, subjected to 150 µm displacement control (Groups I, III)

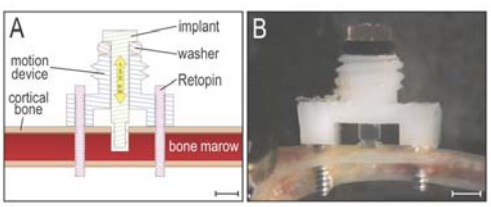

Fig. 1: Motion device shown schematically (left), and mounted on a mouse tibia (right). The main function of the rubber washer is to allow spring-back of the implant after it is displaced downward in an axial direction.

(Scale marker is A and B is 1mm)

RESULTS Net stiffness (k_{net}) increased with time for pin and screw implants in the BIGI (Fig. 3).

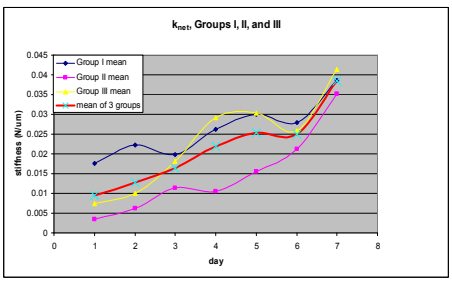

Fig. 3: k_{net} vs. time for pin and screw implants subjected to displacement control (150 or 300 µm, Groups I-III) in BIGI

For screw implants in DBII, the lack of change in k_i over 7 days was consistent with day-1 interdigitation of screws in bone and little change thereafter. However, there was some evidence of interfacial bone resorption in these cases (Fig. 7), perhaps in response to high interfacial strains (Fig. 7).

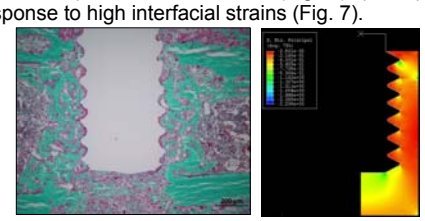

Fig. 7: 7-day interface of screw implant in DBII (left) and compressive principal stress around screw (right)

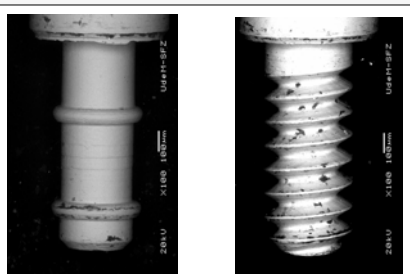

Fig. 2: tips of pin (left) and screw implants (right), Ø = 0.5mm. Implants are made of 70% L-lactide and 30% D,L-lactide, grade LR706 (Midwest Plastics, MN; Medical Micro Machining, Inc., CA) Implants made of titanium have also been tested.

For screws in the DBII, net stiffness (k_{net}) did not show a clear stiffening trend (Fig. 4).

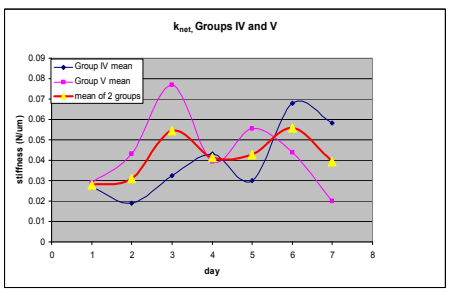

Fig. 4: k_{net} vs. time for screw implants subjected to displacement control (Group IV) and load control (Group V) in DBII

CONCLUSIONS *In vivo* measurements of bone-implant stiffness allowed a non-invasive assessment of healing at the bone-implant interface. Ongoing work is trying to adapt this method for the case of typical dental implants as used in human patients.

REFERENCES

1. Leucht P *et al.* (2007). *Bone* 40(4):919-930
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