White Paper 2 – PLDLLA BoneWelding® Implants provide mechanical strength as long as clinically required

Background and introduction

The degradation of PLDLLA is accomplished by hydrolysis, where water molecules break the initial polymer chains into shorter chains. The physical consequences of the degradation are first a loss in molecular weight, followed by the loss of strength, and in the last step, a loss of mass [1-4]. The rate at which the polymer is degrading depends on many factors: The manufacturing process [5], the sterilization method [5-8], and the length of the polymer chains, i.e., the molecular weight (as measured by the Inherent Viscosity IV value) of the polymer before implantation. The most crucial factor that contributes to the degradation rate is body temperature. The higher the body temperature, the faster the degradation and, consequently, mechanical stability reduces earlier [5, 9, 10].

Stability of the Weldix® Anchor over time (*in vitro*)

The *in vitro* degradation behavior of the Weldix Anchor® was investigated at 37°C, and it showed that the mechanical stability was preserved for 12 months. In contrast, the molecular weight drops to 30% of the initial weight (see *Figure 1)*. This observation shows that although the degradation is in process and the molecular chains are shortened, the Weldix Anchor® showed no loss of mechanical fixation strength during the first 52 weeks. The Weldix Anchor® can maintain its mechanical strength due to its unique design and the anchorage created by the BoneWelding® Technology.

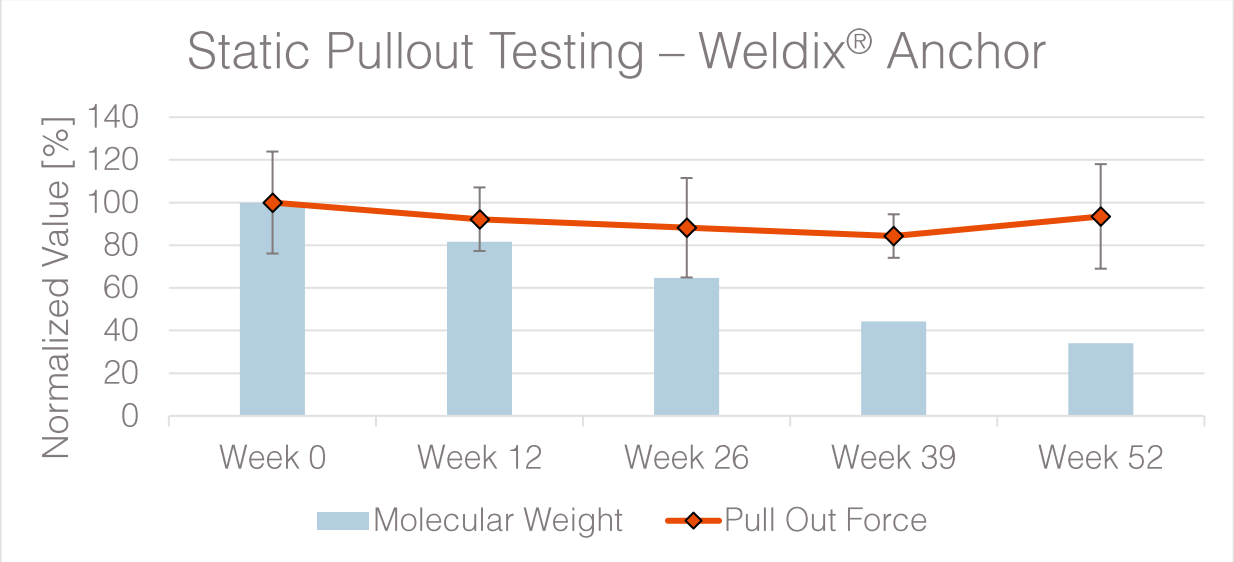

Figure 1: Pull-Out Strength (measured in Sawbones® Block) of Weldix® Anchor for different aging time points ranging from 0 to 52 weeks in 37°C. Although the molecular weight is decreasing, the Weldix® Anchor maintains its mechanical stability due to its design.

Cats and dogs have higher mean body temperatures than humans, which accelerates the degradation. Since the degradation process is hydrolytic and thus governed by thermal activation energy according to the Arrhenius function, a specific acceleration factor can be calculated [9]. As shown in *Table 1*, the Weldix® Anchor will keep its mechanical strength for at least six months when implanted into canines and felines.

Animal	Body Temperature [°C]	Acceleration Factor	Stability loss after [week]
Large Dog	37.5 - 38.6	1.15 - 1.54	33 - 45
Small Dog	38.6 - 39.2	1.54 - 1.8	28 - 33
Cat	37.8 - 39.2	1.25 - 1.8	28 - 41
Sheep	38.9 - 40	1.67 - 2.2	23 - 31
Goat	38.6 - 40.2	1.54 - 2.3	22 - 33

Table 1: Body temperatures and acceleration factor compared to degradation behavior at 37°C [11]. The acceleration factor indicates that PLDLLA implants inserted with BoneWelding® Technology in felines and canines will keep their mechanical strength for at least six months.

Comparison of mechanical performance to a resorbable 2.5mm barbed anchor (*in vitro*)

In vitro comparison between the Weldix® Anchor and a commercially available resorbable 2.5mm barbed anchor was performed to investigate the influence of aging, modelling stability after three months of implantation, on pull-out strength. The Weldix® Anchor showed 70% higher pull-out forces than the barbed anchor initially and more than 100% higher strength after three months (see *Figure 2*). Hence, the Weldix® Anchor will provide more long-term stability compared to a state-of-the-art barbed anchor.

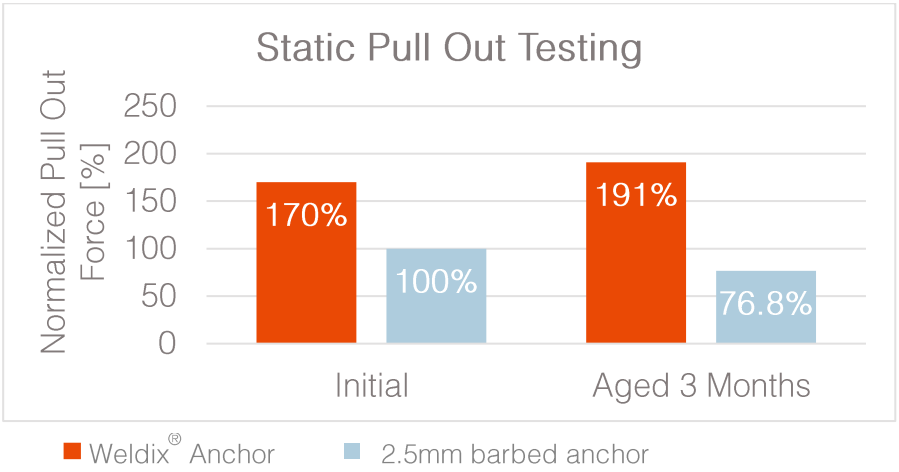

Figure 2: Static Pull Out Testing of a Weldix® Anchor and a commercially available resorbable 2.5mm barbed push-in anchor before and after three months of degradation.

Discussion

The available literature of PLDLLA implants with varying designs and in different animal and clinical studies can be compared to the obtained test results of the Weldix® Anchor. Regarding veterinary applications, one study was found where PLDLLA bone plates were used *in vivo* for fracture fixations in toy breed dogs. The plates showed advanced degradation after two years and led to complete fracture healing to full unity in 10/11 dogs. One out of the eleven implants failed due to a non-union. Most dogs used their surgically repaired limb within the first two weeks after surgery [12]. Pin implants in sheep are comparable to the Weldix® Anchor in small animals regarding mechanical load and animal body temperature. Different values for degradation initiation and completion were found during research and were in accordance with the results obtained in the Weldix® Anchor study. Two studies reported a degradation process after 18 months and complete degradation after 36 months [13] or complete degradation and replacement by bone after 24 months respectively [14]. Another study investigated the difference between cylindrical titanium core implants with a partial PLDLLA coating and the same titanium implants without the polymer coating. The coated implants were inserted with the BoneWelding® Technology into a sheep pelvis model. The mechanical stability was assessed at two weeks and up to 12 months after implantation using a torque removal test. The results are

displayed in *Figure 3* and show a better performance for the coated implants inserted by means of BoneWelding® Technology.

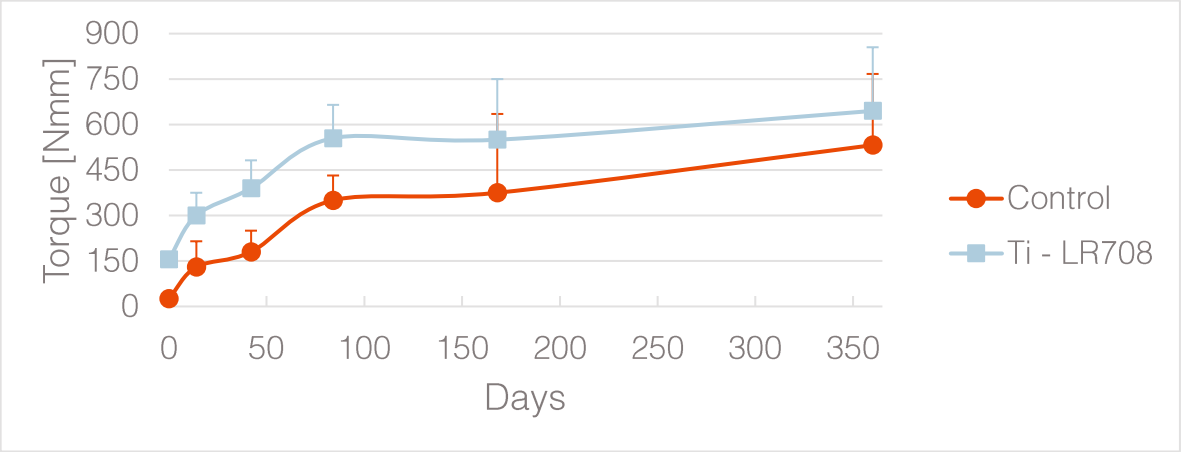

Figure 3: Anchoring strength is increasing for coated (Ti-LR708) and uncoated implants (Control), whereas the coated implants show a better overall performance [15].

An *in vitro* test evaluated the mechanical strength of PLDLLA pins in a three-point bending test. The authors report constant mechanical properties during the first 9 months and a complete loss of mechanical stability after 18 months for pins stored at 37° [7]. Another *in vitro* test evaluated PLDLLA cages in a surrounding temperature of 39°C for 42 weeks. The authors investigated the direct influence of temperature, humidity, and loading rate on PLDLLA cage failure. They concluded that the strength of PLDLLA strongly depends on all three of these factors. Even under a permanent loading that was much below the yield strength itself, they observed that the cages failed due to creep behavior [10]. Furthermore, an *in vitro* study evaluating the strength of PLDLLA plates and screws found that the screws were reaching 97% of their initial mechanical strength after 26 weeks and only 73% after 39 weeks in a test environment at 37° [16].

The Weldix® Anchor can maintain its mechanical stability for longer than the above discussed *in vitro* tests due to the interface geometry that the BoneWelding® Technology creates. During the implantation, the polymer locally liquefies into the surrounding cancellous bone. It creates a homogeneous interface between bone and implant that perfectly distributes the load and prevents peak or notch stresses. This unique interface enables the Weldix® Anchor to retain its mechanical stability for up to one year in human applications and six months in small animals, although the molecular weight has already dropped to 30% of its initial value.

BoneWelding® Technology creates a homogeneous load distribution interface geometry that provides superior mechanical strength. This is even more so since the resulting interface enables the polymer implant to retain its initial mechanical stability, although its molecular weight has drastically decreased in the advancing degradation process. The underlying study results indicate that PLDLLA devices implanted with BoneWelding® Technology keep their initial mechanical properties at least six months after implantation in canine and feline patients.

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