White Paper 7 – Resorbable Pin and Plate implants are beneficial for essentially non-load bearing osteosynthesis

Background and Introduction

The BoneWelding® Technology is a revolutionizing fixation technique that uses ultrasonic energy to anchor a polymer implant into bone. The polymer infiltrates the small cavities in the surrounding cancellous bone by local melting at the implant's surface. The VetWelding Resorb pins and plates are made of 100% biocompatible and fully bioresorbable Poly-D,L-lactic Acid (PDLLA Resomer® R208 (Evonik Röhm GmbH, Darmstadt, Germany)). *In vivio*, degradation of the pins and plates is based on the natural physiological process of hydrolysis, resulting in a complete metabolization of the polymer into H2O and CO2. This paper discusses the mechanical performance during degradation & fracture healing of PDLLA implants in small animals.

The available literature of PDLLA degradation in vitro and animal studies considered together with fracture healing literature present a good understanding of the degradation of the Resorb Pin and Plate System in small animals. Literature of early fracture healing in dogs indicates that in the early stages of healing, approximately three to six weeks postoperatively, the fracture will regain most of the stiffness and strength it reaches at twelve weeks [1-3]. This suggests that, given the appropriate fixation, initial tissue healing is substantially complete within six weeks during which the resorbable implant should maintain most of its strength. Studies have also indicated that clinical fracture healing occurs typically before 8 weeks postoperatively [4, 5]. Depending on the plating technique this can occur as early as four weeks, and regardless of plating or imaging technique, all fractures investigated healed in less than 12 weeks [4].

Literature of PDLLA degradation in vitro indicates that the polymer will maintain its mechanical integrity at 37° C for at least ten weeks [6]. The accelerated degradation in small animals due to higher body temperature indicates the Resorb implants can provide complete stability for at least seven weeks in dogs and cats.
The mechanical performance of the Resorb plates has been demonstrated in vivo in sheep where bone plate construct strength was maintained in the early stages in healing and increased at later stages, indicating bone healing [7, 8]. The degradation of the Resorb implants in sheep is comparable to the degradation in other small animals due to their similar body temperatures (38.9°C - 40°C).

Stability of the Resorb PDLLA plate and pin system over time (in vivo)

Meissner et al. and *Pilling et al.* investigated the stability of Resorb plates using conventional screws or BoneWelding® pins, respectively, in craniotomy model in young sheep and showed that the plates were effective in osteosynthesis in craniofacial surgery [7, 8]. Mechanical properties of the plated osteotomies were evaluated among others by tensile tests, at periods from 1 day to 196 days. Osteosynthesis using the BoneWelding® pin demonstrated significant mechanical superiority over screw osteosynthesis [8] over the entire healing period, even post remodeling (see *Figure 1*). In contrast to the plate-screw system, the ultrasonic insertion of the pins causes the pins to weld to the plates, thus firmly locking the pins with the plates. This allows for much more stable fixation of the fracture, providing better primary stability and, as results indicate, supporting fracture healing.

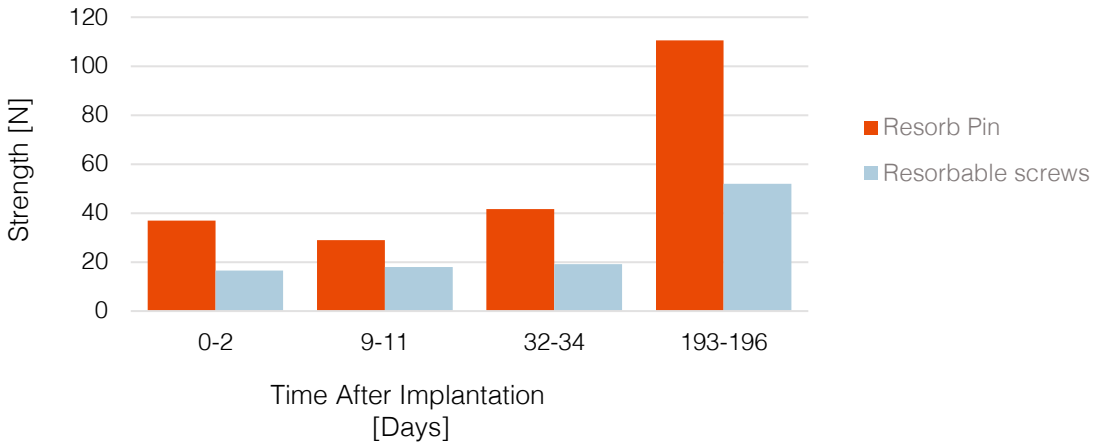

Figure 1: Bone & plate construct strength in a tensile test (a). Strength increases from 32–34 days (5 weeks) to 193-196 days (28 Weeks). BoneWelding® pins show a better overall performance. [8]

Stability of the PDLLA polymer over time (in vitro)

The degradation of PDLLA 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 [9-12]. The rate at which the polymer is degrading depends highly on body temperature. A higher body temperature results in faster degradation and, consequently, mechanical stability reduces earlier [13-15]. *Ruffieux et al.* investigated the in vitro degradation behavior of the PDLLA polymer in detail, investigating the effects of temperature and pH. It was demonstrated that at 37°C, the polymer maintains most of its strength for ten weeks, followed by a rapid decrease in mechanical properties afterward. The degradation was found to obey the Arrhenius equation [6]. Cats and dogs have higher body temperatures than humans, accelerating the degradation. Since the degradation process is governed by thermal activation energy according to the Arrhenius equation. A specific acceleration factor can be calculated and used to predict the polymer degradation process at small animals' body temperatures (See *Table 1*) [14].

Animal	Body Temperature [°C]	Acceleration Factor	Stability loss after [weeks]
Large Dog	37.5 - 38.6	1.08 - 1.26	8-9
Small Dog	38.6 - 39.2	1.26 - 1.38	7-8
Cat	37.8 - 39.2	1.12 - 1.38	7-8

Table 1: Body temperatures and acceleration factor compared to degradation behavior at 37°C [16]. The acceleration factor indicates that PDLLA implants in felines and canines will keep their mechanical strength for at least seven weeks.

Discussion

The data reported above on the influence of body temperature as well as reported for fracture healing indicate that the Resorb PDLLA devices implanted with BoneWelding® Technology keep their initial mechanical properties throughout the healing process allowing complete fracture healing and bone regeneration under non-load bearing applications after implantation in canine and feline patients as illustrated in *Figure 2*.

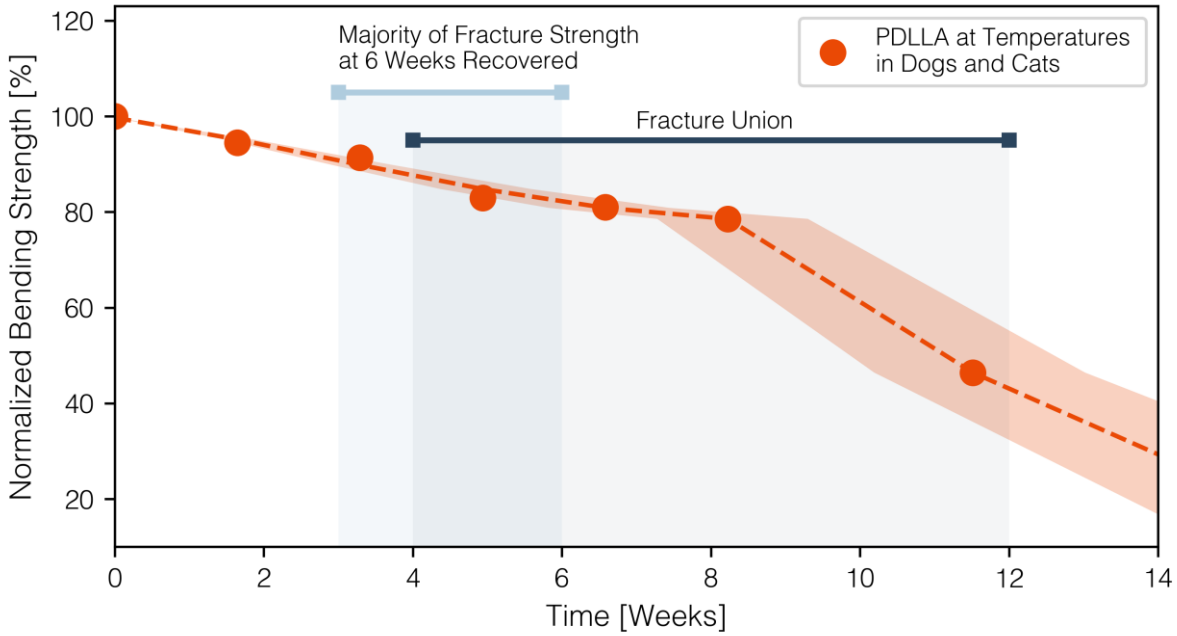

Figure 2: Bending strength of PDLLA throughout fracture healing: Bending strength of PDLLA rods throughout degradation in vitro accelerated for the body temperatures observed in dogs and cats (orange line), Timeframe during which the biological union recovers most of its mechanical strength (light blue line), Timeframe during which clinical union is diagnosed (dark blue line).

It can be concluded that for adequate fracture healing, implants need to retain strength until the initial healing of bone tissue is sufficiently complete, through a period of approximately six weeks. In vitro studies indicate that PDLLA devices implanted in dogs and cats can keep most of their initial mechanical properties at least seven weeks after implantation. Furthermore, this has been verified with Resorb implants through an in vivo study in sheep that showed the plates were effective in osteosynthesis in craniofacial surgery. The above test results and literature indicate that **Resorb PDLLA devices implanted with BoneWelding® Technology keep their initial mechanical properties throughout the healing process allowing complete fracture healing and bone regeneration** in non-load bearing applications after implantation in canine and feline patients.

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