White Paper 1 - Introduction and Summary of BoneWelding® Implant Technology; What makes it superior to metal implants?

Introduction

The BoneWelding® Technology is a revolutionizing fixation technique that uses ultrasonic energy to anchor a polymer implant into bone. The local liquefaction of the polymer infiltrates the small cavities in the surrounding cancellous bone. Since 2005 the BoneWelding® Technology has been a well-established technique in human craniomaxillofacial surgery (SonicWeld Rx®, KLS Martin, Tuttlingen, Germany) [1-4] along with other applications, such as the treatment of hallux valgus; (SonicPin®, Stryker, Mahwah, NJ) [5] or with suture anchors (SF Push-in Anchor, Surgical Fusion Technologies GmbH, Schlieren, Switzerland) [6]. Compared to conventional fixation devices like metal screws, polymer implants applied by the BoneWelding® Technology have the advantage of a drastically reduced application time and providing higher mechanical strength [3, 7-9]. This white paper is the first in a series of white papers introducing specifically the two main biodegradable polymers that are clinically used in combination with the BoneWelding® Technology today:

- Slower resorbing: Poly (L-lactide-co-DL-lactide) 70:30 (Resomer® LR706S, Evonik Röhm GmbH, Darmstadt, Germany), hereafter referred to as PLDLLA.
- Faster resorbing: Poly (DL-lactide) 50:50 (Resomer® R208, Evonik Röhm GmbH, Darmstadt, Germany), hereafter referred to as PDLLA.

The main advantage of bioresorbable polymers in fracture fixation or bone fusion applications is that they are not as rigid as metal implants and hence do not result in stress shielding [10]. They can also gradually shift the load from polymer to the bone while degrading. Furthermore, the need for implant removal is non-existent, as the host body resorbs the implant. This means that a second surgery with attributed risks and costs is unnecessary.

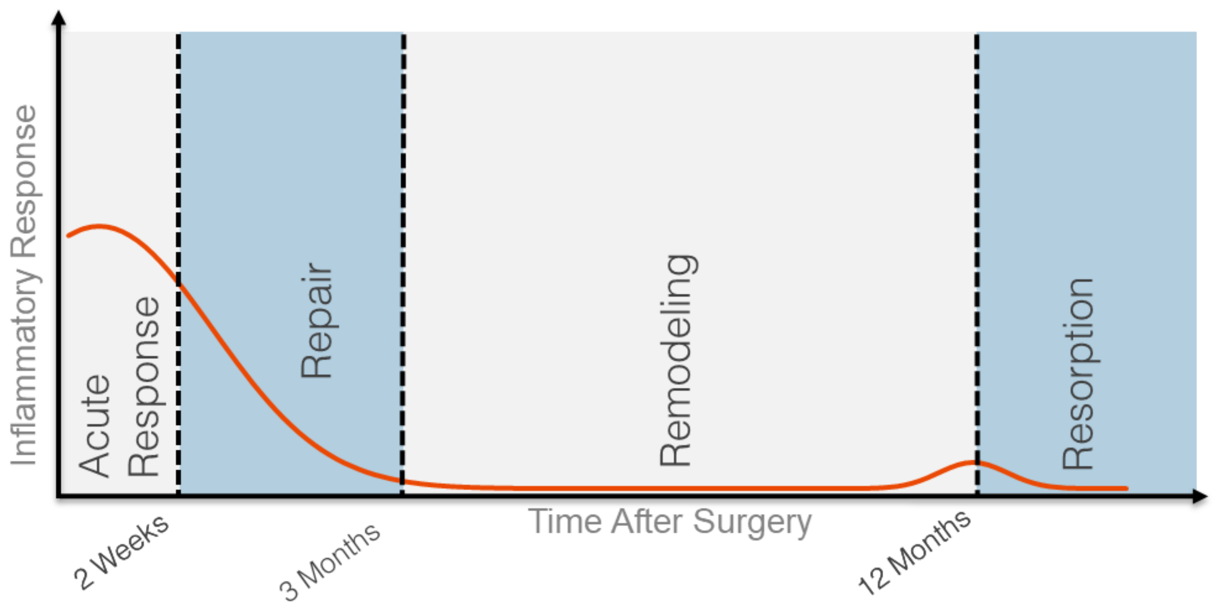

Figure 1: Characteristic biological and material related reactions over time, exemplarily, shown for the slower resorbing PLDLLA, as observed in a sheep model (body temperature between 38.5°C and 39.5°C). The faster resorbing PDLLA completes the resorption process between 6-12 months, and implants are entirely replaced by bone after 12 months.

This white paper series aims to discuss the degradation behavior of PLDLLA and demonstrate its safe use in small animals. To account for the different stages of degradation the implant goes through, each white paper in this series investigates an important phase during the degradation of a bioresorbable polymer. *Figure 1* shows a schematic display of the inflammatory response after surgery (sheep, body temperature between 38.5°C and 39.5°C). The acute inflammatory response is comparable to the one of non-resorbable materials. It decreases during tissue repair and stays very low during tissue remodeling. Then after about 12 months, the late phase of degradation causes a slight increase in the inflammatory response induced by the disintegration and resorption of the polymer. After that, bone can slowly fill the polymer's place before. For the faster resorbing PDLLA, the degradation process and inflammatory response are comparable, but the polymer is replaced by bone after one year instead.

The SF Push-in Anchor (Surgical Fusion Technologies, Switzerland) as well as the pins in the SonicWeld Rx Pin and Plate System (KLS Martin, Germany) use both the so-called 'push in' BoneWelding® Technology, wherein the outer surface of the polymer liquefies through ultrasonic vibration and flows into cancellous bone wherein it solidifies (*Figure 2*). Throughout the white paper series, research and clinical experience related to these two BoneWelding® implants used in human medicine will be discussed to illustrate the influence of fixation technology and material on performance, the different aspects of degradation, and sensitivity to infections. Both implant families have been tested extensively *in vitro* and animal studies (primarily sheep). They have been approved, among others, by the FDA, and their clinical application is extensively covered by numerous peer-reviewed papers. Design and material are identical to the Weldix® Anchor or the Resorb Pin and Plate System, which are offered in veterinary medicine (*Figure* 3).

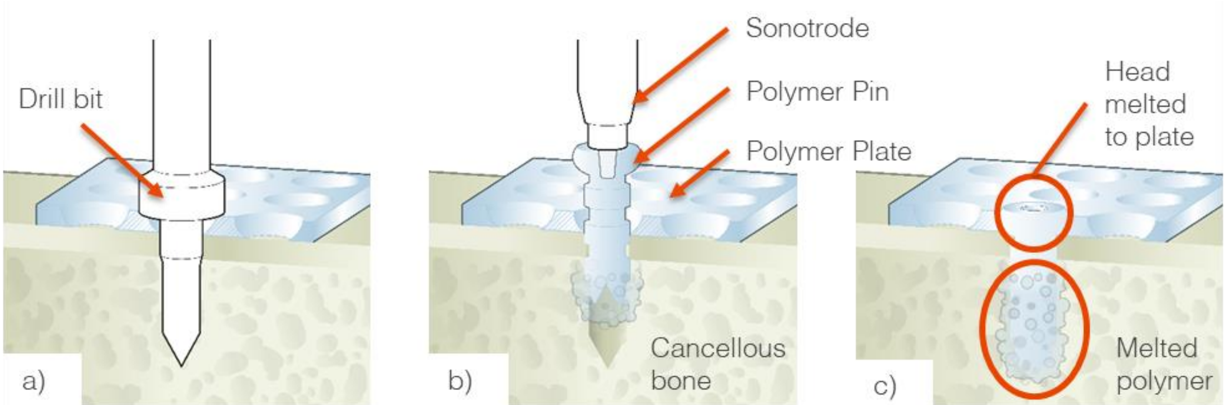

Figure 2 BoneWelding® Technology:
a) Pilot hole is created with a drill bit. b) The polymer pin is ultrasonically inserted into the predrilled hole with a slightly smaller diameter than the pin. c) The ultrasonic vibration causes friction between pin and bone, which causes the polymer to liquefy into the surrounding cancellous bone whereby, in seconds, it creates a unique bonding to the bone. Furthermore, the pin head melts to the plate and creates one implant.

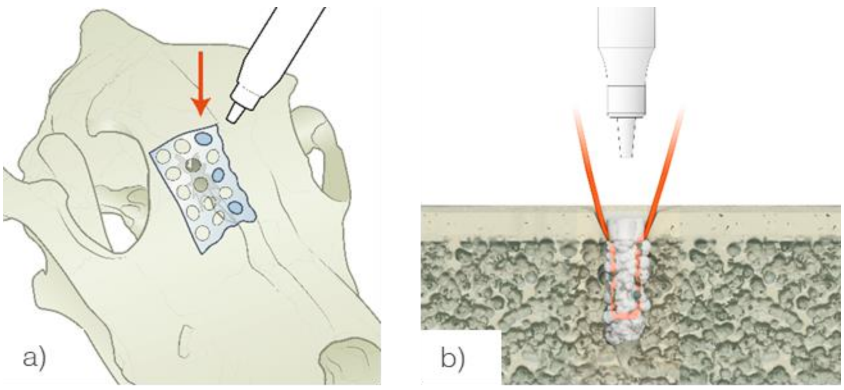

Figure 3 VetWelding Products:

a) Resorb Pin and Plate System (PDLLA)
Diameter: 1.6 mm; drill hole 1.0 mm
Diameter: 2.1 mm; drill hole 1.6 mm

b) Weldix® Anchor (PLDLLA)
Diameter: 2.3 mm, drill hole: 1.8 mm

Summary white paper series VetWelding

The white papers summarized below discuss application specific performances, degradation behavior, inflammatory reactions, and infection rates of such biodegradable polymers, especially, with respect to their application in small animals.

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

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.

White Paper 3 – The BoneWelding® fixation process provides superior fatigue and long-term stability

For dynamic tests, the Weldix® Anchor (drill hole 1.8mm) possesses three times higher pull-out force than the resorbable 2.5mm barbed anchor (drill hole of 2.5mm). Additional creep tests showed 400 times better creep performance of the Weldix® Anchor compared with the barbed anchor. Both are of essential importance to ensuring the upkeep of suture tension even under challenging conditions while minimizing the size of the anchor.

White Paper 4 – Degradation of BoneWelding® Implants does not trigger excessive inflammatory reaction

The results from different animal models and clinical studies all indicate a safe use of biodegradable polymers in small animals; the inflammation is described as non-existent to mild. Slight swelling can occur in subcutaneously placed plates, which is not expected for the implants placed directly in bone by BoneWelding® Technology. In the correct indication, the polymer resorbs completely and transforms into bone without any sign of unwanted histological reaction or even osteolysis

White Paper 5 – BoneWelding® Implants transform into bone after resorption

The presence of degrading PLDLLA does not prevent the bone from growing. Furthermore, it was observed that ultrasonically applied pins could enhance stability by increasing bone-implant contact. Test results of a faster resorbing but otherwise identical polymer pin made out of PDLLA (Resorb Pin and Plates) showed complete resorption and replacement of the drill hole by new bone after one year. The behavior with the slower resorbing PLDLLA (Weldix® Anchor) is expected to be the same but requires rather two years than one. Studies on ultrasonically applied pins in humans showed promising remodeling activity, which is expected to be even better in canines due to the faster canine bone remodeling.

White Paper 6 – PLDLLA BoneWelding® Implants do not create a higher infection risk than titanium

The use of PLDLLA as biodegradable material obliterates the need for reoperation for implant removal. This presents the most relevant advantage over a metallic implant, and with it, the risk of latent infection or an acute infection due to reoperation. For the Weldix® Anchor, where a small pin of PLDLLA is inserted flush with the cortical bone, there is a decreased infection risk as no fibrous capsule is formed over the implant. Furthermore, the BoneWelding® process is a delicate implantation process with a shallow risk of damaging the surrounding viable tissue, which minimizes the risk of device-related infection.

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

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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