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Bio-Integration and Bone Fixation Performance of Continuous Mineral Fiber-Reinforced Implants

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INTRODUCTION

Bio-integration, the integration of an implant into the surrounding bone tissues as it is eliminated, is a characteristic that is associated with bone graft or bone filler materials. Some of these materials are also referred to as osteoconductive or osteostimulative[1]. This term does not apply to most orthopedic fixation implants, such as those produced from metal or PEEK, which are permanent and do not allow the implant site to regenerate to native tissue. Though bioabsorbable polymer implants are eliminated over time, they lack quiescent integration as their degradation has been associated with inflammatory events such as cyst formation and fluid accumulation. Recently, bio-integrative bone fixation implants comprised of continuous mineral fibers and PLDLA polymer were introduced (Fig 1). The high mineral content is intended to encourage an increased bio-integrative response, while the continuous fiber structure provides mechanical bone fixation strength.

OBJECTIVE

To evaluate the long-term bio-integration of fiber-reinforced implants, as well as their ability to maintain fixation in a full load bearing in vivo model**.**

METHODS

Twenty-four rabbits were studied over a 104-week period to evaluate the bio-integration of a fiber-reinforced bone fixation pin. The continuous reinforcing mineral fibers made up approximately 50% of the implant, comprised of elements found in native bone, including calcium, silica, and magnesium. The other 50% was comprised of poly (L-lactide-co-D, L lactide) (PLDLA) at a 70:30, L:DL ratio. Pins were implanted bilaterally, with three 2.0mm fiber-reinforced pins (test) implanted into the mid-shaft of one femur and three 2.0mm PLDLA polymer pins (control) into the mid-shaft of the other femur (Fig 2A). Implantation sites were scored histologically at multiple timepoints to assess bio-integration by means of implant degradation profile, surrounding bone quality and tissue ingrowth.

A separate group of twelve rabbits was studied clinically, radiographically and histologically over the course of 12 weeks to evaluate the 2.0mm fiber-reinforced implant performance, compared to a 2.0mm stainless-steel (k-wire) implanted group, in a lateral femur condyle osteotomy model (Fig 2B) under full load bearing conditions.

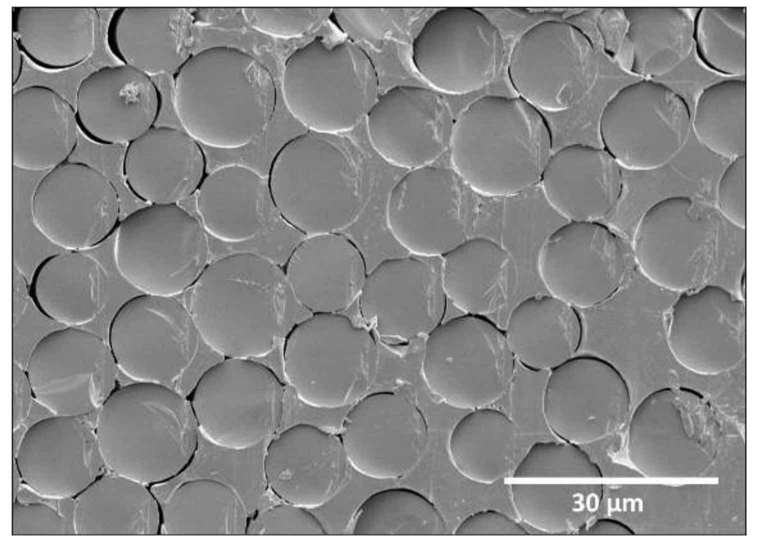

Figure 1. Scanning Electron Microscope (SEM) cross-section of mineral fibers and binding polymer resin.

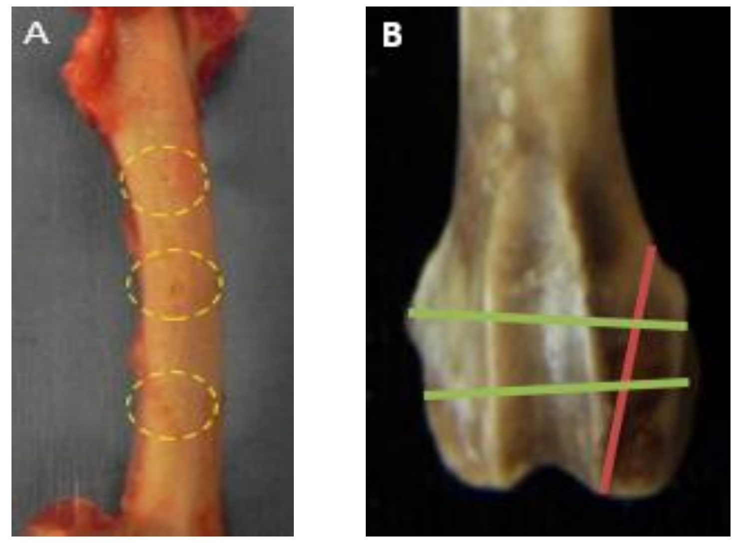

Figure 2. In Vivo implantation models. A: Unicortical implantation of three 2.0mm fiber-reinforced pins in the mid-shaft of a rabbit femur. B: Illustration of the osteotomy model of the lateral femoral condyle. Osteotomy site (orange line); Implants (green lines).

RESULTS

At 104 weeks of implantation, implant material was fully eliminated in 11 out of 12 fiber-reinforced implants and in 6 out of 12 PLDLA implants. Implants were well tolerated and did not raise any safety concerns. The fiber-reinforced group showed increased propensity for bio-integration throughout the course of the study, demonstrated by a more gradual degradation profile and much higher score of tissue ingrowth. Amount of polymer decreased from a score of 4.0±0.0 at 4 weeks to score 1.7±0.5 at week 26, score 1.0±0.0 at week 78 and 0.1±0.3 at 104 weeks. The polymer control underwent abrupt late stage degradation, with little degradation through 78 weeks and amount of polymer dropping from a score of 4.0±0.0 to a score of 0.7±0.8 from 78 to 104 weeks (Fig 3A&B,4). Bone quality was scored 4.0 (mostly lamellar bone) for both groups at 104 weeks.

In the load bearing osteotomy model, all animals in both the fiber-reinforced and metal implanted groups returned to full weight bearing within six days of surgery. At the 12-week timepoint, the fiber-reinforced group demonstrated complete healing (Fig 6) and tight bone-to-implant interface (score of 4.0) with no intervening fibrotic tissue between the implant and the surrounding bone (Fig 5). Bone healing scores of 2.0±0.82 and 1.5±0.71 at 4 weeks and 5.25±0.96 and 3.0 at 12 weeks were evaluated histologically for the fiber-reinforced and metal implanted groups, respectively. Micro CT evaluation demonstrated mean fracture width of 1.692 ± 0.851 and 1.609 ± 0.646 mm at 4 weeks and 1.107 ± 0.455 and 1.205 mm at 12 weeks, for each group, respectively. Both the bone healing score and mean fracture width measurements were statistically indistinguishable between the groups at both time points.

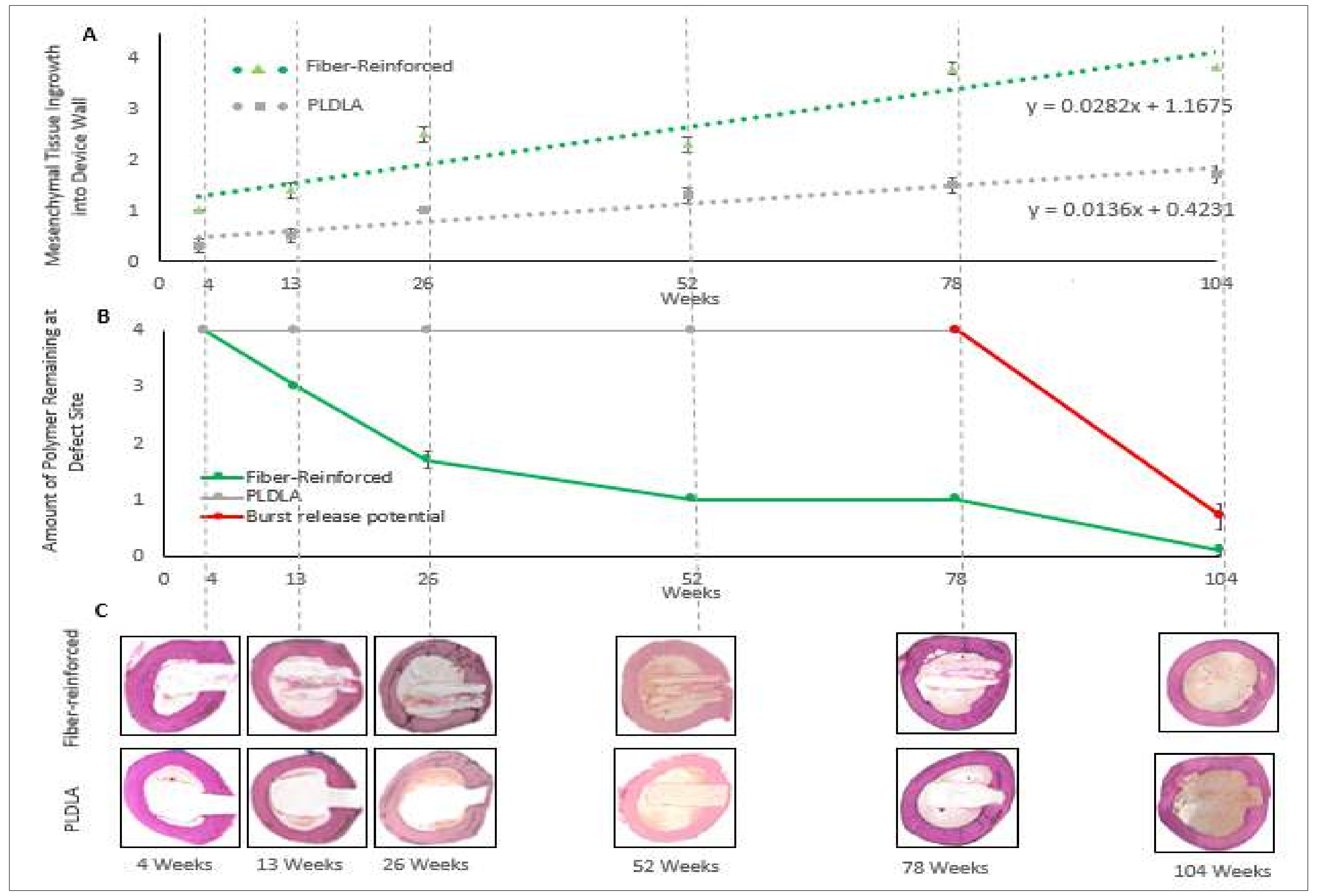

Figure 3. **A**: Mesenchymal tissue ingrowth into device wall scoring matrix (mean±StErr) 0=Absent; 1=Minimal; 2=Mild; 3=Moderate; 4=Marked. **B:** Amount of polymer remaining at defect site (mean±StErr) scoring matrix : 0 = No polymer remains at defect site (complete degradation of polymer); 1 = 1- 25% of polymer remains at defect site; 2 = 26 - 50% of polymer remains at defect site; 3 = 51 - 75% of polymer remains at defect site; 4 = 76 -100% of polymer remains at defect site. **C**: Representative Photomicrographs (H&E). Comparison between Fiber-reinforced and PLDLA polymer-only implants.

Fiber-Reinforced Pin – *12 weeks*

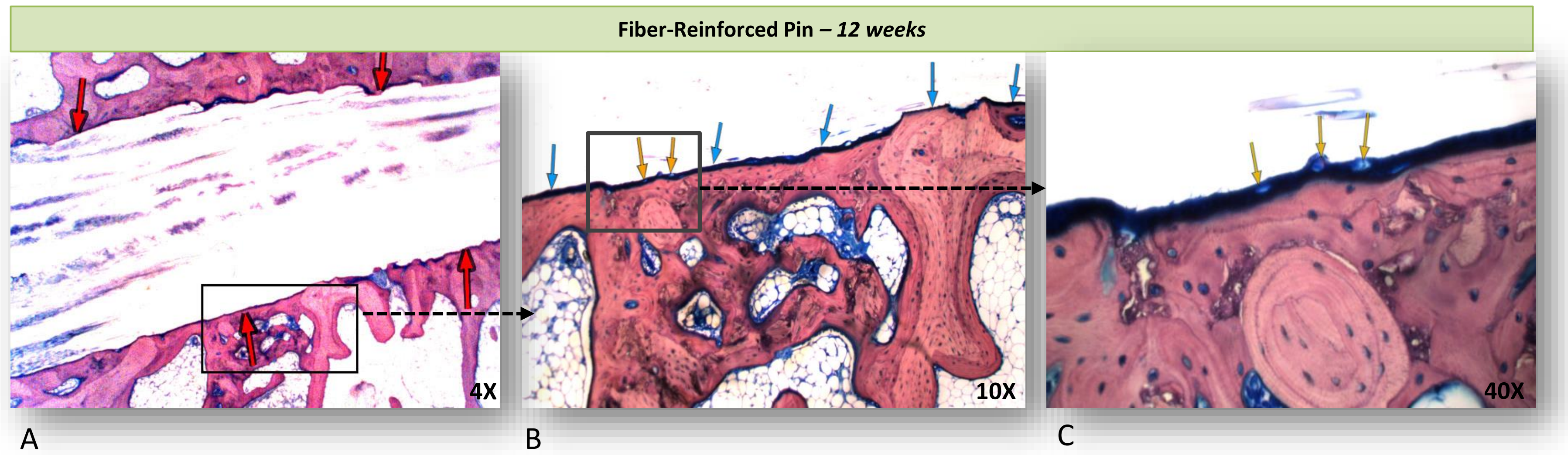

Figure 5. Bone-to-Implant interface at week 12 (SB). A: Red arrows= Bone-to-implant interface with no evidence of fibrotic encapsulation. B: Blue arrows= Direct bone-implant contact; Yellow arrows= Osteoblasts observed at the implant wall surface. C: Yellow arrows= Higher magnification of osteoblasts at the implant wall surface.

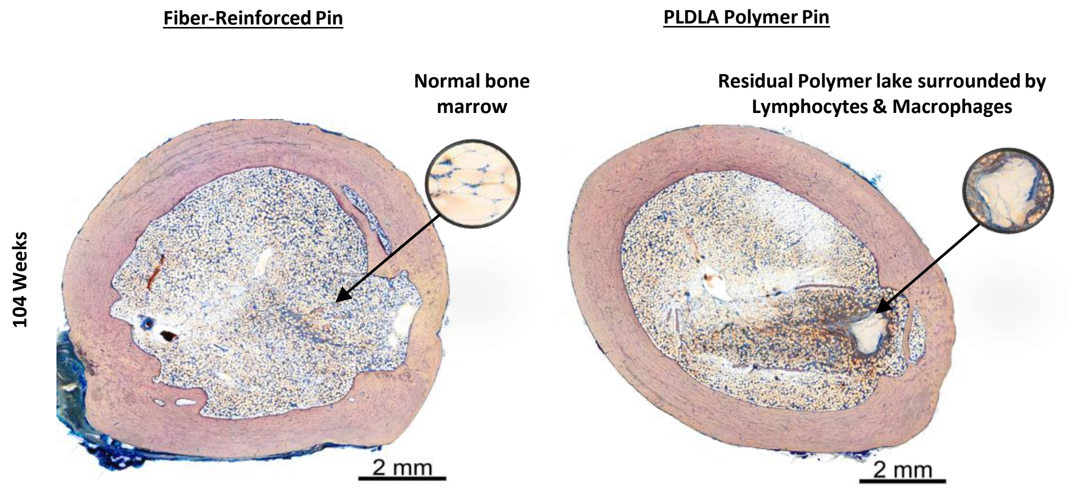

Figure 4. 104 weeks photomicrographs (SB). Comparison between Fiber-Reinforced and PLDLA polymer implants.

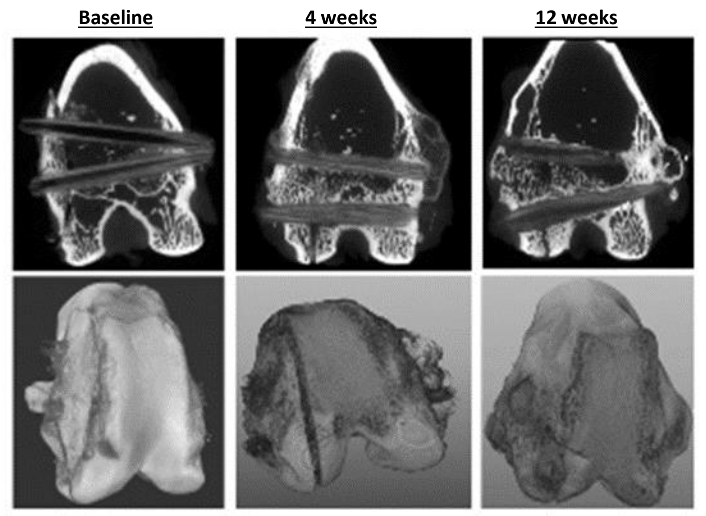

Figure 6. Micro CT of the distal femur following osteotomy fixation of the lateral condyle using fiber-reinforced bone pins. Complete bone healing by 12 weeks.

CONCLUSIONS

This study represents the first long term in-vivo evaluation of mineral fiber-reinforced implants, demonstrating both bio-integration and orthopedic fixation. Quiescent bio-integration is a significant challenge for degradable orthopedic fixation implants. The implants must be mechanically strong for stable fixation while able to gradually integrate with surrounding bone without local adverse effects. Continuous fiber reinforced implants proved the unique potential to meet this challenge with a fiber structure that provides fixation strength and comprised entirely of minerals found in native bone. An increased level of mesenchymal tissue ingrowth combined with the absence of local or systemic adverse tissue response demonstrates excellent bio-integration compared to metal.

BIBLIOGRAPHY

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