Regulation of basalt fibers on PLA scaffold biodegradation

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INTRODUCTION:

Polylactic acid (PLA) is a common biomaterial for sutures, pins, screws, and bone scaffolds in tissue engineering. However, PLA has weak mechanical strength, rapid degradation and acidic products during degradation, which limit its applications as bone scaffolds, especially in the weight bearing situation [1]. A legitimate method to overcome this limitation is to modify PLA structures with reinforcing materials. In this study, we proposed the inclusion of basalt fibers (BF). BF, a silicate-based fiber, has been successfully used in construction industry. Theoretically, its strong mechanical strength can prevent PLA from rapid degradation, and its alkalescence can neutralize the acidic product of PLA. As a first step toward its clinical application, we examined the effects of basalt fibers on the biodegradation of PLA in terms of scaffold morphology, mechanical properties and pH variation.

METHODS:

Scaffold preparation: Basalt fibers (diameter of 8μm) (Shanghai Russia & Gold Basalt Fiber Co.Ltd.) were sectioned into an average length of 2 mm. 15wt% fibers were dispersed uniformly in PLA 1, 4-dioxane solution. Freeze-drying method [2] was used to produce cylindrical BF/PLA scaffolds and pure PLA scaffolds as a control (8 mm in diameter, 15 mm in length).

Scaffold morphology The microstructures of the scaffolds were studied using a scanning electron microscope (SEM, JSM 5610 LV, JEOL).

Mechanical test: The compressive modulus and strength of scaffolds were evaluated with a mechanical testing system (CMT5305, SANS) (1kN load cell). The cross-head speed was 1 mm/min [3].

In vitro degradation: BF/PLA scaffolds and pure PLA scaffolds were immersed separately in phosphate buffer solution for 4 weeks with the initial pH value of 7.40 at 37◦C. pH values were tested weekly.

Statistical Analysis: One-way analysis of variance was performed. All the results were expressed as means ± standard deviations. Statistical significance was set at $p \leq 0.05$.

RESULTS:

BF/PLA scaffolds had microporous structures shown on SEM images, which was similar to those in pure PLA scaffolds (Figures 1a&1b). Approximately 80% of the pores had diameters larger than 100 μm, and basalt fibers were uniformly dispersed in the scaffolds (yellow arrows). After 4 weeks, the structures of BF/PLA scaffolds degraded with decreasing pore wall thickness and the increasing pore size (Figure 1c); in contrast, pure PLA scaffolds further demonstrated erosion evidence, the formation of numerous micro pores in the pore wall (blue arrows, Figure 1d).

The compressive modulus of BF/PLA scaffolds reached up to 6.70 ± 0.22 MPa, threefold higher than that of pure PLA scaffolds (1.80 ± 0.19 MPa); the compressive strength of scaffolds increased from 0.31 ± 0.01MPa to 0.96 ± 0.04 MPa. After 4 week degradation, BF/PLA scaffolds maintained the compressive modulus of 6.00 ± 0.21 MPa, and the strength of 0.88 ± 0.07 MPa. However, the compressive modulus and strength of pure PLA scaffolds decreased to 0.87 ± 0.17 MPa and 0.11 ± 0.01 MPa, respectively.

pH value of the PLA solution stayed at 7.40 during the first week, and then decreased to 7.28 at week 4. In comparison, the pH value of BF/PLA scaffold dropped significantly smaller and was 7.38 at week 4 ($p<0.05$ at week 2-4) (Figure 2).

DISCUSSION:

An ideal scaffold should act as a three-dimensional template for bony growth. The porous structure of BF/PLA scaffolds with a diameter of at least 100 μm will be favorable for cell adherence and exchange of nutrition [4]. The inclusion of 15wt% fibers did not alter the mechanism of pore formation. PLA scaffolds alone had low compressive properties which might not be sufficient to withstand higher loads in weight bearing applications. BF/PLA scaffolds increased the initial strength of pure PLA scaffolds by 210%. After 4 week degradation, the compressive strength of PLA decreased by 65%. Fast degradation of PLA would cause sudden strength decrease, which limited its application only to fast-healing bone disorders. The presence of basalt fibers slowed PLA degradation rate, the compressive strength decreased only by 8% after 4 week degradation, maintaining the mechanical properties of the scaffolds for a longer time. In addition, the alkaline oxide constituents of basalt fibers, such as CaO, MgO, K_2O or Na_2O, neutralized the acid degradation of PLA, avoiding the nonbacterial inflammations aroused by the acidic product. Future investigation of basalt fiber contents may be needed to optimize the regulation of PLA scaffold degradation.

In conclusion, basalt fibers played a significant role in regulating PLA scaffold degradation with enhancement of the mechanical properties, reduction of the degradation rate and neutralization of the acid products of PLA degradation.

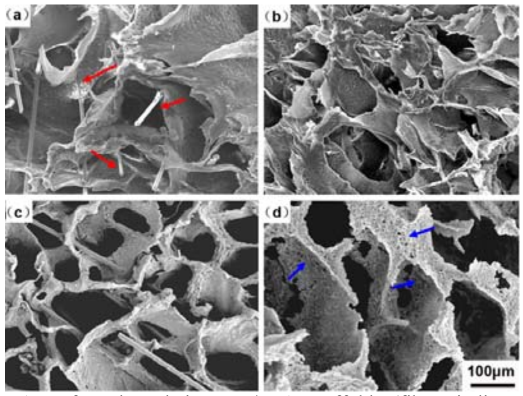

Figure 1. Before degradation, BF/PLA scaffolds (fibers indicated by yellow arrows) showed microporous structures with pore diameters of greater than 100 μm (a), similar to pure PLA scaffolds (b); after degradation, the structures of BF/PLA scaffolds degraded with decreasing pore wall thickness and the increasing pore size (c), pure PLA scaffolds further demonstrated erosion evidence, the formation of numerous micro pores in the pore wall (blue arrows) (d).

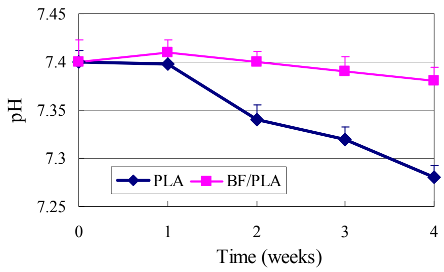

Figure 2. pH value of pure PLA scaffolds decreased from 7.40 to 7.28; and pH value of BF/PLA scaffolds decreased from 7.40 to 7.38 after degradation.

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