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1. BACKGROUND AND PURPOSE

The incorporation of lead-free piezoelectric ceramics into biocompatible polymers represents a promising strategy to enhance bone tissue regeneration through electromechanical stimulation. Polymer-ceramic composites can generate electrical signals under mechanical loading, promoting cell proliferation and differentiation. However, their performance depends on key factors such as ceramic composition, polymer matrix, polarization state, and external stimulation. Low-Intensity Pulsed Ultrasound (LIPUS) has emerged as an effective, non-invasive method to activate the piezoelectric effect, enhancing biological responses.

This work evaluates the biological performance of polarized polymer-ceramic composites under ultrasound (US) stimulation, with an emphasis on their suitability as platforms for bone tissue engineering (BTE). Polylactic acid (PLA) and Poly(vinylidene fluoride) (PVDF) were employed as polymer matrices, while barium titanate (BT) or $x\text{BaZr}_{0.2}\text{Ti}_{0.8}\text{O}_3-(1-x)\text{Ba}_{0.7}\text{Ca}_{0.3}\text{TiO}_3$ (BCZT) served as the ceramic phase. These ceramic fillers are lead-free and exhibit relatively high piezoelectric coefficients.

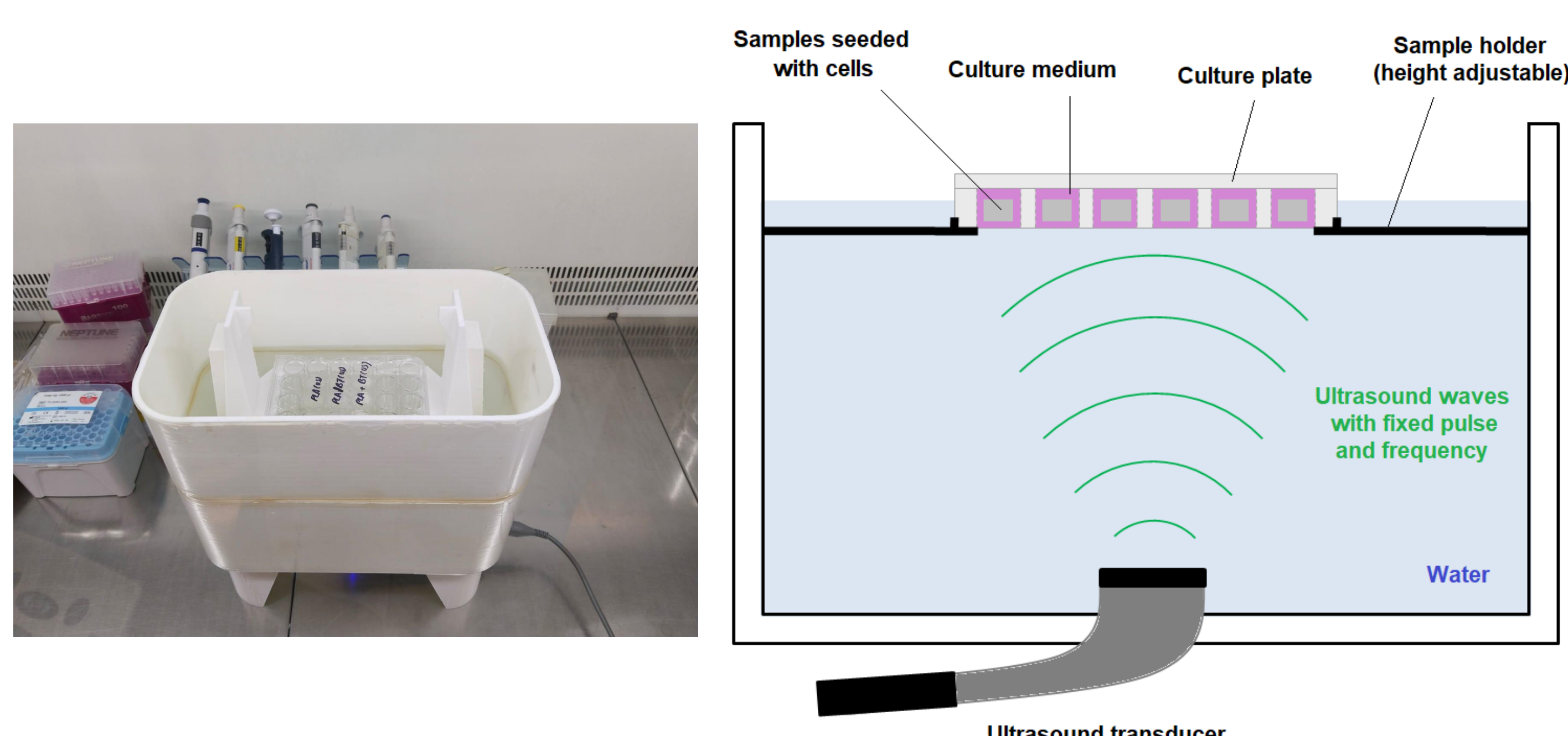
2. METHODS

BCZT powders were synthesized by mechanosynthesis and thermally treated (1450 °C, 4 h), yielding a pseudocubic perovskite structure with optimal composition ($x = 0.4$). Disc-shaped composites ($\varnothing 15 \text{ mm} \times 1 \text{ mm}$) were manufactured by compression moulding using PLA or PVDF matrices combined with BT or BCZT at different volume fractions.

Samples were polarized at 100 °C under an electric field of 4 kV/mm for 30 min, maintaining the field during cooling to align dipoles and enhance piezoelectric response.

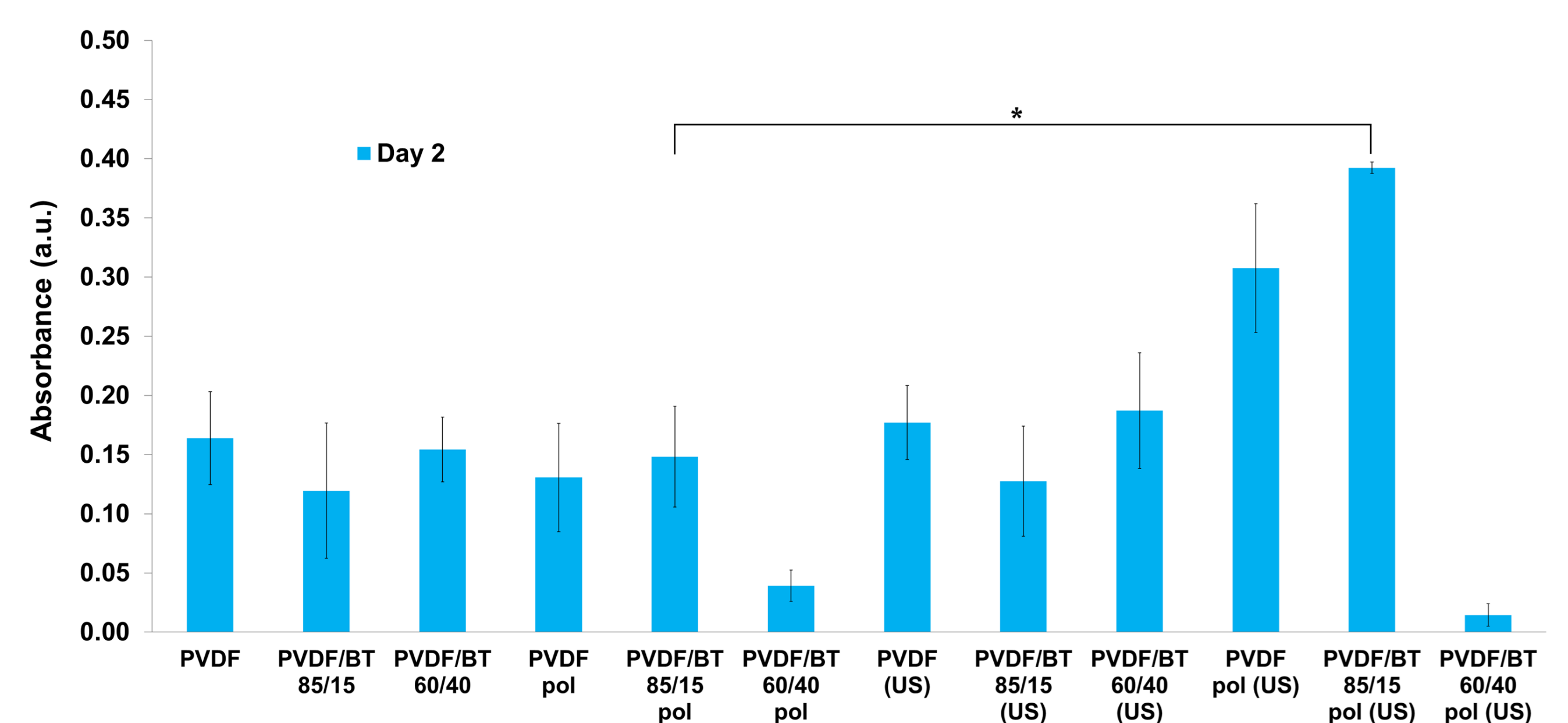


A custom LIPUS system was developed, consisting of a sonicator, a water tank, and a sample holder enabling indirect US application. The selected parameters were: 1 MHz frequency, 30 mW/cm² intensity, pulsed mode (1 ms, 100 Hz), and daily exposure times of 15–20 min. Human osteoblastic cells (hFOB 1.19) were seeded onto the samples. Cell viability was evaluated using CCK-8 assays (450 nm) at different time points (1–7 days), considering the effects of material composition, polarization, and US stimulation.

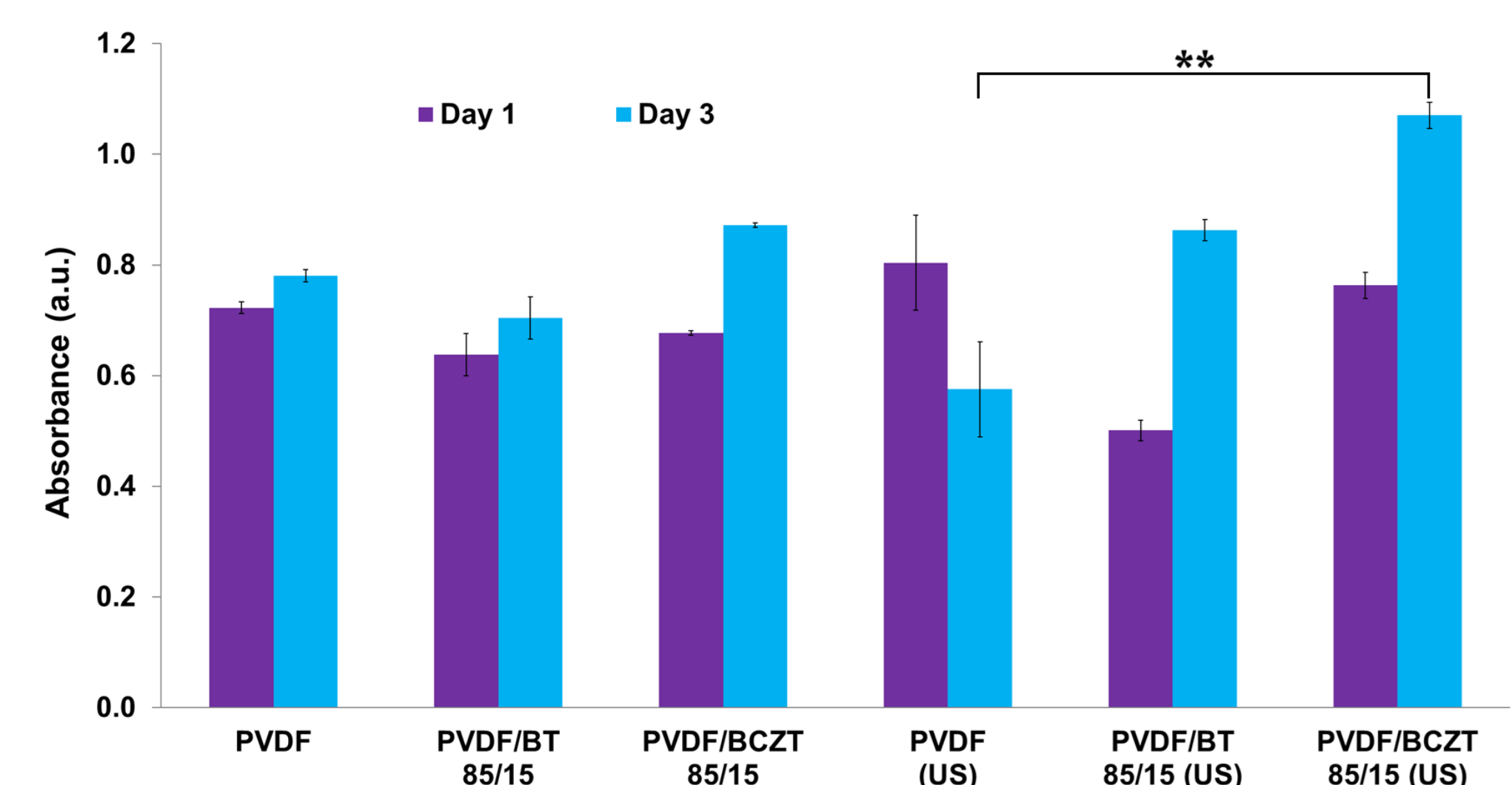


3. RESULTS

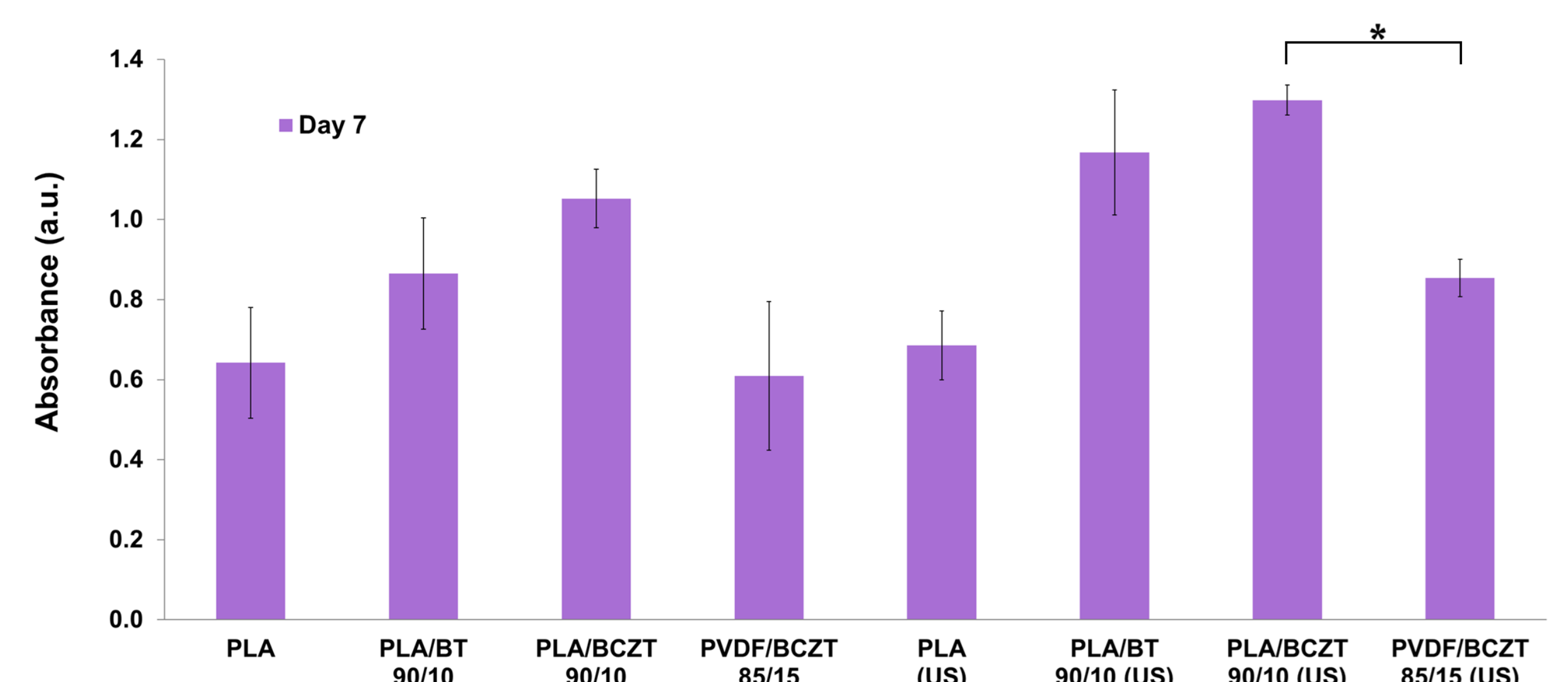
Polarized composites exposed to US exhibited significantly enhanced cell viability, whereas no significant differences were observed in non-polarized or non-stimulated conditions. However, high ceramic content (e.g., PVDF/BT 60/40) reduced biological performance after polarization, indicating limited dipole alignment.



Within polarized PVDF-based systems, the highest cell viability was obtained for the PVDF/BCZT 85/15 (%v/v) composite.



Despite the higher intrinsic piezoelectricity of PVDF, PLA-based composites showed superior long-term cell viability. The best overall performance was achieved by polarized PLA/BCZT 90/10 samples under US stimulation, reaching the highest viability after 7 days.



4. CONCLUSIONS

- Polarized polymer-ceramic composites activated by LIPUS enhance osteoblastic cell viability via piezoelectric stimulation.
- BCZT-based composites outperformed conventional BT systems, particularly under polarization and US conditions.
- The polymer matrix critically influences the biological response, with PLA-based systems showing superior cell compatibility.
- Overall, PLA/BCZT composites under US stimulation emerge as promising candidates for BTE.

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