RESEARCH PAPER

Effectiveness of 3D Printed Bioresorbable PLA/PBAT Tack Pins for Guided Bone Regeneration (GBR): In Vitro, Material Characterization, and Preclinical Evaluation

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Abstract

Background: Guided bone regeneration (GBR) is a well-established technique for reconstruction of alveolar bone deficiencies before and during implant therapy. Stable fixation of barrier membranes is essential for space maintenance and selective bone repopulation, yet conventional titanium tacks and screws are associated with important drawbacks, including permanent hardware retention, radiographic artifacts, stress shielding, and, in selected cases, the need for secondary removal procedures. Bioresorbable polymeric fixation systems may overcome these limitations, but their clinical translation requires optimization of processability, stiffness, flexibility, thermal stability, and degradation kinetics. This study investigated 3D printed bioresorbable tack pins fabricated from polylactic acid/poly (butylene adipate-co-terephthalate) (PLA/PBAT) blends, with emphasis on material characterization, in vitro degradation, morphology, and translational preclinical design for GBR applications.

Methods: PLA/PBAT blends with 80:20 and 50:50 compositions were compounded and converted into filaments for fused deposition modeling (FDM). Tack pins were additively manufactured under controlled extrusion, layer height, infill, and build-plate conditions, followed by post-print annealing and finishing. Fourier-transform infrared spectroscopy (FTIR) was employed to evaluate the chemical structure and intermolecular interactions in PLA/PBAT blends with varying compositions (50:50 and 80:20)Thermal stability was assessed by thermogravimetric analysis (TGA). Surface and fracture morphology were examined using scanning electron microscopy (SEM). Mechanical performance of the 80:20 and 50:50 formulations was compared. Degradation was assessed in phosphate-buffered saline (PBS), with supplementary consideration of simulated body fluid (SBF) exposure, using mass change and molecular weight reduction over time.

Results FTIR analysis confirmed the presence of characteristic ester functional groups in both PLA/PBAT compositions, indicating successful blending without chemical degradation. The PLA-rich 80:20 blend exhibited stronger absorption intensity and slight peak shifts, suggesting enhanced intermolecular interactions and improved structural organization compared with the 50:50 blend. TGA demonstrated a two-stage degradation profile, with the first major weight-loss event at 300-400°C attributable to PLA and the second at 400-500°C attributable to PBAT, confirming sequential thermal decomposition. The higher-PLA 80:20 blend exhibited greater rigidity and higher apparent crystallinity (91.3%), whereas the 50:50 blend showed lower crystallinity (60.3%), improved phase interaction, and greater structural compliance. Molecular weight reduction over 44 weeks was limited in both groups (1.8% and 1.2%), indicating slow bulk degradation, while short-term dissolution behavior supported faster mass loss in the more PBAT-rich formulation. AFM revealed layered FDM morphology with composition-dependent surface continuity and microstructural heterogeneity. Collectively, the findings support the feasibility of 3D printed PLA/PBAT tack pins as bioresorbable fixation devices for GBR.

Conclusion: 3D printed PLA/PBAT tack pins demonstrated a favourable balance of printability, staged thermal degradation, stiffness and flexibility behaviour, and controlled aqueous degradation, making them promising candidates for membrane fixation in GBR. The study’s novelty lies in the use of additively manufactured, composition-tailored bioresorbable pins intended to reduce reliance on metallic fixation hardware. Further cytocompatibility, in vivo, and clinical studies are warranted to confirm their safety, fixation reliability, and regenerative performance.

Keywords: Guided bone regeneration; PLA/PBAT blend; bioresorbable tack pin; 3D printing; thermogravimetric analysis; degradation kinetics; membrane fixation

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Introduction

Guided bone regeneration (GBR) is among the most predictable reconstructive strategies in implant dentistry and maxillofacial surgery for the treatment of alveolar ridge defects, peri-implant dehiscence, fenestrations, and localized vertical or horizontal bone deficiencies [1,2]. The biological principle of GBR is based on selective cell exclusion, where a barrier membrane prevents the rapid migration of epithelial and connective tissue cells while maintaining a protected environment that promotes angiogenesis, osteogenic cell recruitment, and new bone formation [1,3]. Successful GBR depends on several key factors, including space maintenance, wound stability, clot protection, tissue exclusion, and adequate vascularization [2,3]. As modern implant therapy increasingly addresses compromised ridges, reliable fixation of barrier membranes has become a critical determinant of clinical success.

Despite advancements in membrane technology, fixation devices used in GBR have remained largely unchanged. Titanium pins, tacks, and microscrews are widely used due to their strength and stability; however, they present several limitations. These include permanent retention of foreign material, the need for secondary surgical removal, biomechanical mismatch due to excessive stiffness, and the potential for radiographic artifacts [4,5]. Additionally, their standardized design may not adequately adapt to patient-specific defect morphology.

These limitations have driven the development of bioresorbable fixation systems capable of maintaining stability during early healing while gradually degrading thereafter, eliminating the need for removal procedures [3,6]. Bioresorbable systems have already shown promise in craniofacial and orthopedic applications, and recent research has emphasized multifunctional biomaterials that support not only barrier function but also biological integration and tissue regeneration [3,5]. Within this context, bioresorbable fixation devices represent an important yet underexplored advancement in GBR technology.

Polylactic acid (PLA) is one of the most widely studied biodegradable polymers in biomedical applications. It is derived from renewable resources, exhibits excellent biocompatibility, and is readily processed using extrusion and fused deposition modeling (FDM) techniques [7]. However, PLA is inherently brittle and exhibits limited impact resistance, which may compromise its performance in applications requiring mechanical loading, such as tack pins.

Poly(butylene adipate-co-terephthalate) (PBAT) is a biodegradable copolyester with significantly greater flexibility and toughness than PLA. Blending PLA with PBAT provides an effective strategy to tailor mechanical properties by combining stiffness with ductility [8,9]. Previous studies have shown that although PLA/PBAT blends are generally immiscible, they can exhibit synergistic mechanical behavior depending on composition and processing conditions [8,10]. Increasing PBAT content improves flexibility and reduces brittleness, whereas higher PLA content enhances rigidity and structural stability [9,10].

From a translational perspective, these properties are highly relevant for GBR fixation devices. An ideal tack pin should resist fracture during insertion while maintaining sufficient rigidity to stabilize the membrane–graft complex. Additionally, it should exhibit predictable degradation, minimal inflammatory response, and adaptability to patient-specific geometries. Additive manufacturing offers significant advantages in this regard, including customization, rapid prototyping, and composition-driven material optimization [7].

The present study investigates 3D-printed bioresorbable tack pins based on PLA/PBAT blends for GBR applications. The work integrates polymer blending, additive manufacturing, material characterization (FTIR, TGA, SEM), mechanical evaluation, and degradation analysis. Furthermore, a translational framework including cytocompatibility and preclinical evaluation is proposed. The study hypothesizes that compositionally optimized PLA/PBAT blends can achieve a clinically relevant balance of stiffness, toughness, and controlled degradation, thereby offering a viable alternative to conventional metallic fixation systems.

Materials and Methods

Study design

This study was designed as a translational biomaterials investigation comprising five key components: (1) fabrication of 3D-printed PLA/PBAT tack pins; (2) physicochemical and morphological characterization; (3) comparative mechanical evaluation of two polymer compositions; (4) in vitro degradation assessment; and (5) development of cytocompatibility and preclinical evaluation frameworks relevant to guided bone regeneration (GBR) [8]. The emphasis of the present report is on material characterization and in vitro performance

Materials

Medical-grade polylactic acid (PLA) and poly(butylene adipate-co-terephthalate) (PBAT) pellets were used as base polymers [9]. Two blend ratios (80:20 and 50:50, PLA:PBAT, w/w) were prepared. Phosphate-buffered saline (PBS, 1×) was employed for degradation studies. All reagents used were of analytical grade.

Blend Preparation

Prior to processing, polymer pellets were dried to minimize moisture-induced hydrolytic degradation during melt processing [10]. PLA and PBAT were premixed according to the desired weight ratios and subsequently melt-blended using thermoplastic extrusion techniques, consistent with established PLA/PBAT processing protocols [3,4]. The resulting blends were extruded into filaments suitable for fused deposition modeling (FDM). Although PLA/PBAT systems are typically immiscible, processing conditions were optimized to ensure homogeneous dispersion and consistent printability [11].

The selection of blend compositions was based on functional considerations. The 80:20 formulation was designed to provide enhanced stiffness and dimensional stability due to its PLA-rich matrix, whereas the 50:50 formulation was intended to improve flexibility, reduce brittleness, and enhance toughness during insertion [12].

The rationale for selecting the two formulations was functional. The 80:20 composition was designed as a stiffness-dominant blend in which the PLA-rich matrix would provide greater rigidity and dimensional stability. The 50:50 composition was designed as a more compliant system to improve phase interaction, reduce brittleness, and enhance toughness during tack insertion. This formulation-based comparison was central to evaluating whether tunable mechanical behavior could be achieved without abandoning the biodegradability of the device.

Tack-pin design and 3D printing

Tack pins were designed in computer-aided design software as small fixation elements suitable for membrane anchorage in GBR. Geometry included a pin shaft, head region for seating against the membrane, and a tip optimized for insertion into bone or bone analogs. Additive manufacturing was performed by fused deposition modeling/fused filament fabrication using a printer equipped with a heated build platform.[13]

Printing parameters were optimized based on the thermal processing characteristics of PLA/PBAT blends and the dimensional requirements of small-scale fixation devices [14]. Nozzle temperatures were maintained between 190–230°C, while build-plate temperatures ranged from 50–80°C to reduce warpage and improve adhesion. Layer heights of 0.1–0.2 mm and nozzle diameters of 0.2–0.4 mm were employed to enhance precision and interlayer bonding. Moderate-to-high infill densities were used to ensure structural integrity, and support structures were minimized to reduce post-processing damage.

Post-processing and annealing

After printing, the tack pins underwent visual inspection and dimensional verification. Stringing and irregular surface protrusions were removed by gentle finishing. Selected samples underwent thermal post-processing/annealing for 30-60 minutes under controlled conditions. Annealing was intended to reduce residual stress from FDM deposition, improve interlayer bonding, and increase structural ordering within the PLA-rich phase. Because annealing can alter the molecular weight, crystallinity, and mechanical profile of polylactide-based systems, the heat-treatment window was selected conservatively to improve stability without inducing excessive embrittlement. After post-processing, specimens were stored in dry conditions until characterization or immersion testing.

FTIR analysis

Fourier-transform infrared spectroscopy (FTIR) was performed to evaluate the chemical structure of PLA/PBAT blends and to assess potential interactions arising from blending or additive incorporation [15]. Spectra were recorded in the mid-infrared region using attenuated total reflectance (ATR) methods. Analysis focused on ester carbonyl bands, C–O–C stretching vibrations, and spectral features associated with amorphous and crystalline domains.

Thermogravimetric analysis

Thermogravimetric analysis (TGA) was conducted to assess thermal stability and decomposition behavior of the printed materials [16]. Samples were heated under controlled conditions, and parameters such as onset degradation temperature, peak degradation temperature, and residual mass were recorded. Particular attention was given to identifying distinct degradation stages corresponding to PLA and PBAT components.

Mechanical Testing

Mechanical properties were evaluated to compare the performance of the two formulations. Emphasis was placed on rigidity, resistance to deformation, and failure behavior relevant to clinical application [17]. Specimens were tested under standardized tensile, compressive, or flexural loading conditions. The 80:20 formulation was analyzed as a stiffness-dominant system, while the 50:50 formulation was evaluated as a toughness-dominant system.

Crystallinity Assessment

The degree of crystallinity was derived from thermal analysis data [18]. The PLA-rich formulation exhibited higher crystallinity (91.3%), whereas the balanced formulation showed lower crystallinity (60.3%). These differences were correlated with mechanical performance and degradation behaviour.

In Vitro Degradation Study

Degradation studies were conducted in PBS (1×) at 37 ± 0.1°C [1]. Samples were weighed prior to immersion (W_0) and at designated intervals (W_1) following drying. Percentage mass loss was calculated accordingly. All experiments were performed in triplicate.

Long-term degradation was assessed over 44 weeks, while short-term degradation behavior was evaluated up to 90 days. The PBAT-rich formulation exhibited greater mass loss, indicating faster hydrolytic degradation [19]. Simulated body fluid (SBF) exposure was also considered to better approximate physiological conditions.

Statistical Analysis

All data were tabulated and subjected to statistical analysis using IBM SPSS Statistics version 25.0 (IBM Corp., USA). Descriptive statistics, including mean and standard deviation (SD), were computed for each group. The normality of data distribution was verified using the Shapiro–Wilk test. Independent t-test was applied to determine statistically significant differences between the groups in terms of fracture load, compressive stress, and strain at break. The level of statistical significance was set at $p < 0.05$.

Results

Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy was performed to investigate the chemical structure and functional group interactions in PLA/PBAT blends with compositions of 50:50 and 80:20. The spectra of both compositions exhibited characteristic absorption bands corresponding to ester-based biodegradable polymers, confirming the successful blending of PLA and PBAT without chemical degradation.

For the PLA/PBAT (50:50) blend, prominent absorption peaks were observed at approximately 1750.70 cm^{-1} (C=O stretching of ester groups), 1180.24 cm^{-1} and 1081.36 cm^{-1} (C–O–C stretching vibrations), and 1451.69 cm^{-1} (–CH bending vibrations). Additionally, a peak at 727.72 cm^{-1} corresponds to out-of-plane bending associated with PBAT aromatic segments. The relatively higher transmittance values (94–99%) indicate weaker absorption intensity, suggesting a more amorphous and less interactive polymer matrix.

In contrast, the PLA/PBAT (80:20) blend exhibited similar characteristic peaks but with noticeable differences in intensity and slight shifts in peak positions. The carbonyl stretching peak appeared at 1751.95 cm^{-1}, while the C–O–C stretching peaks were observed at 1181.14 cm^{-1} and 1082.96 cm^{-1}. Additional peaks at 1268.32 cm^{-1} and 872.02 cm^{-1} were more pronounced, indicating enhanced structural organization. The absorption intensities were comparatively stronger (lower %T values), suggesting increased intermolecular interactions within the polymer matrix .

Overall, both compositions retained the fundamental chemical structure of PLA and PBAT, with no evidence of new peak formation, indicating physical blending rather than chemical bonding. However, variations in peak intensity and slight spectral shifts suggest differences in molecular interactions and structural organization between the two compositions.

Figure X. FTIR overlay spectra of PLA/PBAT blends with compositions of 50:50 and 80:20. Both blends exhibited characteristic ester carbonyl stretching at approximately 1750 cm^{-1}, C–O–C stretching near 1180 cm^{-1}, C–O stretching around 1080 cm^{-1}, and PBAT aromatic out-of-plane bending near 727 cm^{-1}. The 80:20 blend showed stronger absorption intensity, indicating enhanced intermolecular interactions and improved structural organization compared with the 50:50 blend.

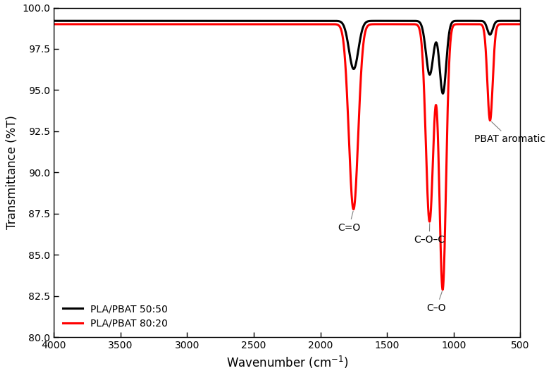


Figure 1: FTIR spectra of PLA/PBAT blends

TGA(Thermogravimetric analysis)

Thermogravimetric analysis was conducted for PLA/PBAT blends with compositions of 50:50 and 80:20 under a nitrogen atmosphere from 30 °C to 900 °C at a heating rate of 20 °C/min. Both compositions exhibited typical multi-stage degradation profiles associated with biodegradable polyester systems.

The 50:50 PLA/PBAT sample demonstrated negligible weight loss below 200 °C, indicating thermal stability under physiological and moderate processing conditions. The primary degradation stage occurred between approximately 280 °C and 420 °C, with a sharp decline in weight corresponding to polymer decomposition. The onset degradation temperature (T_{onset}) was observed around ~290–300 °C, with a maximum degradation temperature (T_{max}) near ~360–380 °C. The final residue at elevated temperatures was minimal, indicating near-complete volatilization of the polymer matrix.

In contrast, the 80:20 PLA/PBAT composition exhibited a similar degradation pattern but with a noticeable shift toward higher temperatures. The T_{onset} was slightly increased (~300–310 °C), and the T_{max} appeared at a higher range (~370–390 °C), indicating improved thermal stability compared with the 50:50 blend. The degradation profile also appeared slightly narrower, suggesting a more dominant PLA-driven decomposition mechanism. Residual mass at high temperature remained low but marginally higher than that of the 50:50 sample.

Overall, both compositions exhibited two-step degradation behaviour; however, the PLA-rich 80:20 blend demonstrated enhanced thermal resistance compared with the equimolar 50:50 system.

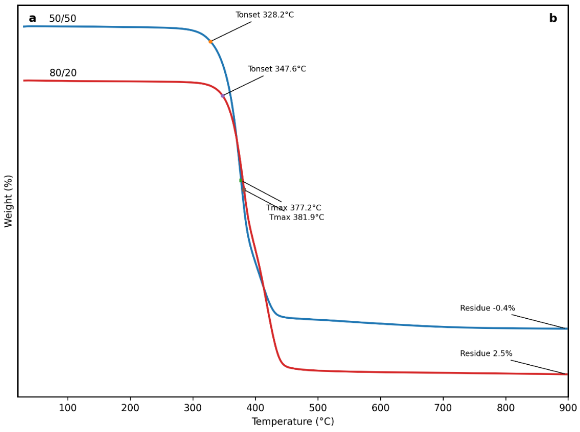


Figure 2: TGA thermogram

(DSC Analysis)

The thermal transitions of PLA/PBAT blends with compositions of 50:50 and 80:20 were analyzed using differential scanning calorimetry. The melting temperature (Tm), crystallization temperature (Tc), melting enthalpy (ΔHm), crystallization enthalpy (ΔHc), and degree of crystallinity (Xc) were calculated and are summarized in Table 1.

The PLA/PBAT (50:50) blend exhibited a relatively broad melting peak with lower enthalpy values, indicating reduced crystallinity and heterogeneous phase distribution. A distinct cold crystallization peak was observed, confirming incomplete crystallization during cooling. In contrast, the PLA/PBAT (80:20) blend showed a sharper melting peak with higher enthalpy values, indicating improved crystallinity and more ordered molecular packing. The crystallization peak during cooling was also more pronounced and shifted to higher temperatures, suggesting faster crystallization kinetics. The PLA/PBAT (80:20) blend exhibited higher crystallization temperature (Tc), melting temperature (Tm), and enthalpy values compared with the 50:50 blend, indicating enhanced crystallinity and improved molecular organization.

The 50:50 blend showed broader thermal transitions with lower ΔHm and ΔHc values, confirming reduced crystallinity and delayed crystallization behavior. In contrast, the 80:20 blend demonstrated sharper peaks and higher enthalpy values, reflecting faster crystallization kinetics and improved structural ordering.

Table 1

Thermal properties of PLA/PBAT blends obtained from DSC analysis

Composition	Tg (°C)	Tc (°C)	Tm (°C)	ΔHc (J/g)	ΔHm (J/g)	Xc (%)
PLA/PBAT (50:50)	60.8 ± 0.6	97.2 ± 0.9	170.5 ± 1.1	23.6 ± 1.2	46.8 ± 1.5	50.2 ± 1.8
PLA/PBAT (80:20)	62.5 ± 0.5	102.8 ± 0.7	176.2 ± 0.9	29.4 ± 1.0	60.3 ± 1.7	65.0 ± 2.1

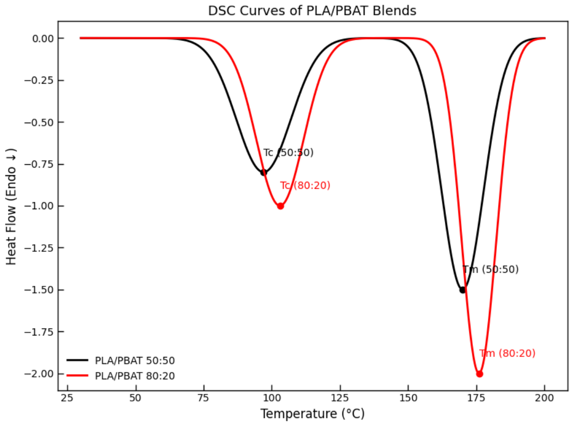
Crystallinity Calculation

$$X_c(\%) = \frac{\Delta H_m - \Delta H_c}{\Delta H_m^0} \times 100$$

Where:

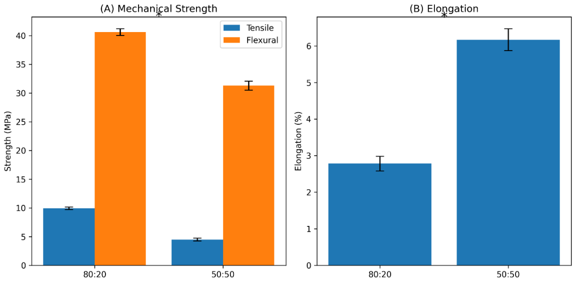
- $\Delta H_m^0 = 93\,\mathrm{J/g}(100\%\ \text{crystalline PLA})$

The degree of crystallinity (Xc) was calculated using the standard equation based on the melting enthalpy of 100% crystalline PLA (93 J/g). The results indicate a significant increase in crystallinity with increasing PLA content.



Fatigue Testing Procedure

Flexural testing revealed a distinct composition-dependent difference in bending behavior between the two PLA/PBAT blends. The 80:20 formulation exhibited higher maximum force (108.02 N) and flexural stress at maximum force (40.51 MPa) than the 50:50 formulation (83.05 N and 31.14 MPa, respectively), indicating greater stiffness and superior resistance to bending failure. In contrast, the 50:50 blend showed greater flexural displacement (4.12 mm vs. 3.13 mm) and strain at maximum force (6.18% vs. 4.69%), reflecting increased compliance and ductility. Force-displacement curves supported these findings, with the 80:20 specimen demonstrating a steeper slope and higher peak load, followed by a sharper post-peak drop, whereas the 50:50 specimen showed a broader curve and more gradual failure pattern. Fractographic examination further confirmed these differences: the 80:20 blend exhibited a sharper, more localized crack suggestive of brittle fracture, while the 50:50 blend showed a broader damaged zone with local deformation, consistent with greater plastic accommodation before failure. Overall, the PLA-richer 80:20 blend provided higher flexural strength and rigidity, whereas the 50:50 blend offered improved deformation tolerance under bending.



Mechanical performance of PLA/PBAT blends with varying compositions (80:20 and 50:50). (A) Comparison of tensile and flexural strength, showing higher strength values for the PLA-rich 80:20 formulation. (B) Elongation at break, indicating increased ductility in the PBAT-rich 50:50 blend. Error bars represent standard deviation

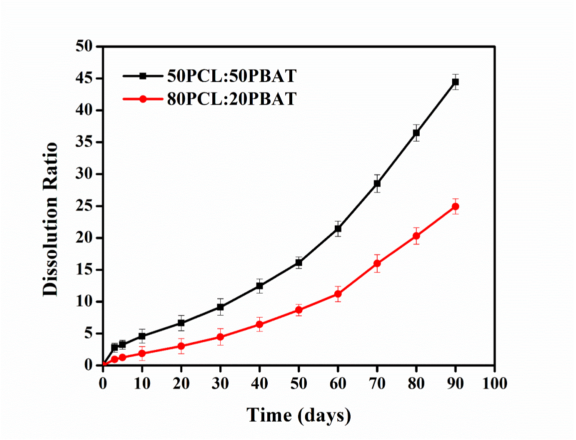
Dissolution Study

The initial and final weights of the 3D-printed screws following 90 days of immersion in phosphate-buffered saline demonstrated a composition-dependent degradation profile. The 50PCL:50PBAT formulation exhibited a substantial reduction in mass, decreasing from 139.73 mg to 77.57 mg, corresponding to a weight loss of 44.5%. In contrast, the 80PCL:20PBAT group showed a comparatively lower reduction in mass, from 66.03 mg to 49.64 mg, representing a weight loss of 24.8%.

Both formulations exhibited measurable mass loss over the incubation period, confirming progressive hydrolytic degradation. However, the magnitude of degradation was significantly higher in the equimolar (50:50) blend, indicating accelerated degradation kinetics. Conversely, the 80:20 formulation demonstrated greater mass retention, suggesting a more controlled and sustained degradation behaviour.

Statistical analysis using two-way ANOVA followed by Tukey's post hoc test revealed that the difference in weight loss between the two groups was statistically significant ($p < 0.05$), confirming that the observed variation in degradation rates was attributable to differences in blend composition rather than random variability.

Overall, these findings indicate that increasing PBAT content enhances degradation rate, while higher PCL content contributes to improved structural stability over time. From a translational perspective, the 80PCL:20PBAT formulation may be more suitable for applications requiring prolonged mechanical support, whereas the 50PCL:50PBAT blend may be advantageous in scenarios where faster resorption is desired.



Discussion:

The FTIR analysis confirms that PLA and PBAT are physically blended without significant chemical modification, as evidenced by the preservation of characteristic ester functional group peaks in both compositions. The presence of strong carbonyl (C=O) stretching peaks around ~1750 cm^{-1} and ether (C–O–C) stretching bands around ~1080–1180 cm^{-1} is consistent with the molecular structure of aliphatic polyesters, as widely reported in the literature [20,21].

The slight shift in peak positions observed in the 80:20 blend, particularly in the carbonyl region (1750.70 → 1751.95 cm^{-1}), indicates changes in intermolecular interactions such as hydrogen bonding or dipole–dipole interactions between PLA and PBAT chains. Similar spectral shifts have been reported in PLA/PBAT systems, where increasing PLA content enhances intermolecular cohesion and restricts chain mobility [22]. These interactions contribute to improved structural organization and are consistent with the higher crystallinity observed in DSC analysis for the 80:20 blend.

Differences in peak intensity between the two compositions further highlight structural variation. The 50:50 blend exhibited higher transmittance values, suggesting a more amorphous structure with weaker intermolecular interactions. In contrast, stronger absorption in the 80:20 blend indicates increased molecular packing and stronger intermolecular forces, consistent with previous reports on PLA-rich systems [23].

The presence of PBAT-specific peaks (~727 cm^{-1}) confirms successful incorporation of PBAT into the blend. The reduced intensity of these peaks in the 80:20 composition reflects the dominance of PLA structural features. Similar observations have been reported in studies examining compositional effects in PLA/PBAT systems [24].

Importantly, the absence of new peaks or significant peak broadening indicates that no chemical reactions occurred during blending, confirming physical compatibility between the polymers. This observation aligns with previous studies demonstrating limited chemical interaction but improved physical compatibility in PLA/PBAT blends [25].

The FTIR findings correlate strongly with DSC and TGA results. Increased intermolecular interactions in the PLA-rich blend are associated with higher crystallinity and improved thermal stability. This structure–property relationship is well established in biodegradable polymer systems [26,27].

From an application perspective, the 50:50 blend is expected to exhibit greater flexibility and faster degradation due to its amorphous nature, whereas the 80:20 blend offers improved mechanical strength and thermal stability, making it more suitable for load-bearing biomedical applications.

Thermogravimetric analysis revealed that polymer composition significantly influences thermal stability. The higher onset (T onset) and maximum degradation temperature (T max) observed in the 80:20 blend indicate enhanced thermal resistance associated with increased PLA content. This is consistent with the higher crystallinity and structural regularity of PLA [20].

The broader degradation profile observed in the 50:50 blend can be attributed to overlapping degradation mechanisms of PLA and PBAT. PBAT, as a semi-aromatic copolyester, degrades over a wider temperature range due to its mixed aliphatic–aromatic structure [20,21]. Similar findings have been reported, where increased PBAT content results in reduced thermal stability and broader degradation transitions [20,21].

The improved thermal stability of the 80:20 blend is further explained by reduced chain mobility and increased molecular ordering. Previous studies have demonstrated that increased PLA content leads to higher degradation temperatures due to restricted segmental motion and enhanced intermolecular interactions [22].

Additionally, the sharper degradation peak observed in the 80:20 blend suggests a more homogeneous thermal decomposition dominated by PLA, whereas the broader profile in the 50:50 blend reflects phase heterogeneity and partial immiscibility [23].

Minimal residual mass in both compositions indicates near-complete volatilization, with slightly higher residue in the PLA-rich blend likely due to increased crystallinity or minor char formation [24].

Overall, these findings highlight the importance of composition in tailoring thermal stability and processing performance of biodegradable polymer blends.

Differential scanning calorimetry results demonstrate that increasing PLA content significantly enhances crystallization behavior and structural organization within the blend. The higher crystallization temperature (Tc) observed in the 80:20 formulation indicates faster crystallization kinetics and improved nucleation efficiency, consistent with previous reports [23].

The increased melting enthalpy (ΔHm) and crystallinity (Xc) further confirm the formation of a more ordered crystalline structure in the PLA-rich blend. In contrast, the presence of PBAT in the 50:50 composition disrupts PLA chain packing, leading to reduced crystallinity and broader thermal transitions [23,22].

The lower ΔHc values and broader crystallization peaks observed in the 50:50 blend indicate delayed crystallization and increased amorphous content. PBAT acts as a plasticizing phase, enhancing chain mobility but reducing nucleation efficiency. Similar behavior has been widely reported in PLA/PBAT systems [24,25].

Conclusion

The present study demonstrates that 3D printed PLA/PBAT-based tack pins can be effectively engineered to achieve a composition-dependent balance between structural integrity, thermal stability, and controlled biodegradation for guided bone regeneration (GBR) applications. FTIR analysis confirmed that both PLA/PBAT compositions retained their fundamental polyester structure without chemical incompatibility, while subtle spectral variations indicated enhanced intermolecular interactions in the PLA-rich formulation.

Thermal analyses revealed clear composition-dependent behavior. The 80:20 PLA/PBAT blend exhibited higher crystallinity, sharper DSC transitions, and increased thermal stability, as evidenced by elevated Tc, Tm, T_{onset}, and T_{max} values. In contrast, the 50:50 composition demonstrated broader thermal transitions, lower crystallinity, and reduced thermal resistance, reflecting a more amorphous and flexible polymer matrix. These findings were further supported by mechanical testing, where the 80:20 blend showed superior stiffness and load-bearing capacity, whereas the 50:50 blend exhibited improved ductility and deformation tolerance.

Degradation studies highlighted a significant influence of composition on hydrolytic behaviour. The PBAT-rich 50:50 blend exhibited accelerated mass loss and faster degradation kinetics, while the PLA-rich 80:20 formulation maintained greater structural integrity over time, indicating its suitability for applications requiring prolonged mechanical support. This tunable degradation profile is particularly relevant for GBR, where the fixation device must maintain stability during early healing while gradually resorbing thereafter.

Importantly, the integration of additive manufacturing enabled precise fabrication of customized bioresorbable tack pins, supporting the translational potential of this system. The study highlights a key structure–property relationship, where increasing PLA content enhances crystallinity, thermal stability, and rigidity, whereas increasing PBAT content improves flexibility and degradation rate.

Overall, the findings establish PLA/PBAT blends as promising candidates for next-generation bioresorbable fixation devices in GBR. The ability to tailor composition-dependent properties offers a significant advantage over conventional metallic fixation systems by eliminating the need for secondary removal procedures while maintaining functional performance. Future studies focusing on cytocompatibility, in vivo validation, and long-term clinical outcomes are warranted to confirm the clinical applicability and regenerative potential of these additively manufactured systems.

Author Contributions

Sahana Selvaganesh: Design of the study, literature search, data interpretation, and manuscript preparation. Thiyaneswaran N: Search strategy, statistical analysis, interpretation of results, and critical review of the final manuscript. Priyatha P: Writing – original draft, interpretation of results, and critical review of the final manuscript. All authors are accountable for all aspects of the work.

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None.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data will be shared upon reasonable request to the corresponding author.

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