LOMA LINDA UNIVERSITY
School of Dentistry

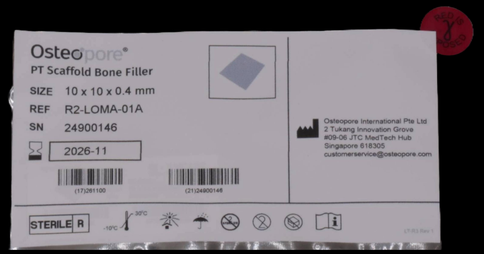
Biodegradable Polycaprolactone (PCL) Membrane for Bone Augmentation: A Comparative In Vitro Analysis of 3D Printed Scaffolds

Dr. Saud. S. Alajmi, Dr. Jaime Lozada, Dr. Aladdin Al Ardah, Dr. Josehp Lee, Dr. Zhe. Zhong, Dr. Ekaterina Zernitckaia

Academy of Osseointegration

Introduction

Barrier membranes play a critical role in guided bone regeneration by stabilizing grafts and maintaining space for bone formation. While collagen membranes are widely used due to their biocompatibility, their rapid degradation may compromise regenerative outcomes. This study clinically evaluates and compares the biodegradation behavior of a collagen membrane and a PCL/β-TCP scaffold under simulated conditions to assess their suitability for maintaining space during guided bone regeneration.



Biodegradable Polycaprolactone (PCL) Membrane for Bone Augmentation: A Comparative In Vitro Analysis of 3D Printed Scaffolds

LOMA LINDA UNIVERSITY
School of Dentistry

Saud. S. Alajmi, Jaime Lozada, Aladdin Al Ardah, Joseph Lee, Zhe. Zhong, Ekaterina Zernitckaia

Academy of Osseointegration

Material and Methods

1- Sample Size

- Seventy-two (72) samples were evaluated: a commercial collagen membrane and a 3D-printed PCL/B-TCP scaffold.
- Samples were standardized in size and thickness prior to testing.

Fig1: 36 PCL Group: Osteopore® custom-printed scaffolds (75% PCL / 25% β-TCP).

Fig2: 36 Collagen Group: OSSIX® Plus compressed membranes.

2- Degradation media

- Specimens were immersed in four solutions:

Fig3: Trypsin.

Fig4: Simulated body fluid (SBF).

Fig5: Phosphate-buffered saline (PBS).

Fig6: Simulated body fluid (SBF) with Collagenase.

3- Measurements

- Weight loss and thickness changes were recorded at baseline and predetermined time points.

Fig7 :Mitutoyo IP65 digital micrometer was used to measure thickness.

Fig8: (METTLER TOLEDO®) was used for high-precision weight measurements.

4- Scanning Electron Microscopy

- Morphology was analyzed using scanning electron microscopy (SEM)

Fig8: Specimen mounting setup used for SEM preparation.

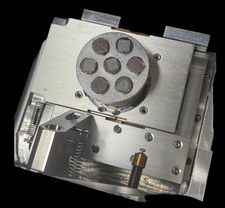


Fig9: Scanning electron microscope. (Thermo Fisher Scientific Quanta™ FEG 250) used for high-resolution imaging of the membranes.

Biodegradable Polycaprolactone (PCL) Membrane for Bone Augmentation: A Comparative In Vitro Analysis of 3D Printed Scaffolds

Saud. S. Alajmi, Jaime Lozada, Aladdin Al Ardah, Joseph Lee, Zhe. Zhong, Ekaterina Zernitckaia

LOMA LINDA UNIVERSITY
School of Dentistry

Academy of Osseointegration

Results

1- Statistical Analysis

- The collagen membrane showed rapid degradation, particularly in enzymatic solutions. The PCL/β-TCP scaffold demonstrated slower, more controlled degradation across all solutions.

Table 1
Two-way ANOVA for weight at final time point : Membrane × Solution.

Effect	df	SS	F	p
C(membrane)	1	425.833	22.95	<0.001
C(solution)	3	182.835	3.28	0.026
C(membrane):C(solution)	3	867.840	15.59	<0.001
Residual	64	1187.438		

Table 2
Two-way ANOVA for thickness at final time point : Membrane × Solution.

Effect	df	SS	F	p
C(membrane)	1	0.236	100.78	<0.001
C(solution)	3	0.069	9.88	<0.001
C(membrane):C(solution)	3	0.108	15.33	<0.001
Residual	64	0.150		

- Weight loss and thickness reduction were significantly greater for collagen over time.

Diagram 1: Thickness Vs Time in all the solutions

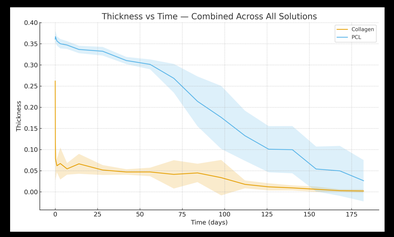
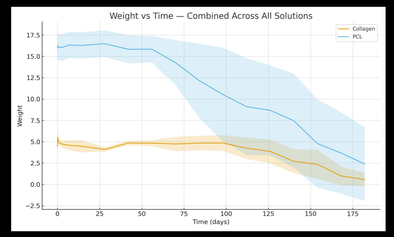


Diagram 2: Weight Vs Time in all the solutions



2- SEM Analysis

- SEM analysis revealed early surface breakdown in collagen, while PCL/β-TCP maintained structural integrity longer

SEM series of Commercial collagen membrane

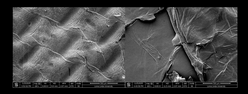


Fig10: Collagen in Trypsin.

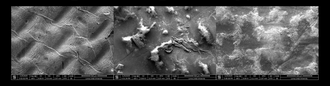


Fig12: Collagen in Simulated body fluid.

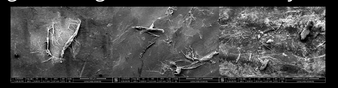


Fig14: Collagen in Phosphate-buffered saline.

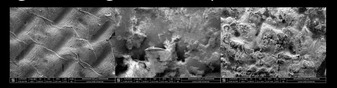


Fig16: Collagen in Simulated body fluid with Collagenase

SEM series 3D-printed PCL/B-TCP scaffold

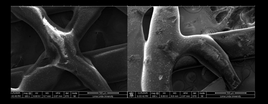


Fig11: PCL in Trypsin.

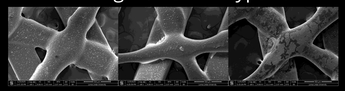


Fig13: PCL in Simulated body fluid.

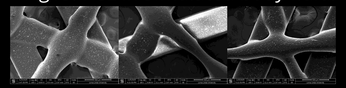


Fig15: PCL in Phosphate-buffered saline.

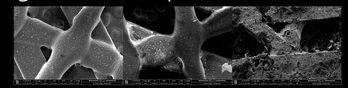


Fig17: PCL in Simulated body fluid with Collagenase.

Fig18: Collagen end-point image showing extensive enzyme-induced membrane degradation.

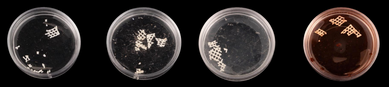


Fig19: Collagen end-point image showing extensive enzyme-induced membrane degradation.

LOMA LINDA UNIVERSITY
School of Dentistry

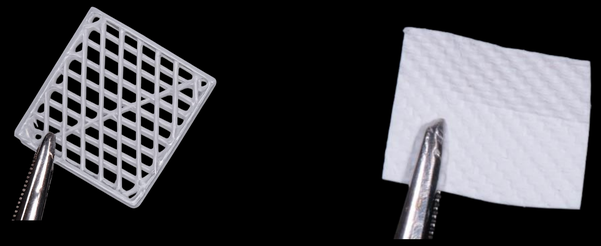
Biodegradable Polycaprolactone (PCL) Membrane for Bone Augmentation: A Comparative In Vitro Analysis of 3D Printed Scaffolds

Saud. S. Alajmi, Jaime Lozada, Aladdin Al Ardah, Joseph Lee, Zhe. Zhong, Ekaterina Zernitckaia

Academy of Osseointegration

Discussion

The null hypothesis was rejected, as significant differences were observed in the degradation behavior of the collagen membrane and the PCL/β-TCP scaffold. The collagen membrane exhibited more rapid degradation, particularly under enzymatic conditions, whereas the PCL/β-TCP scaffold showed a slower and more controlled degradation profile.



These results align with previous reports describing accelerated enzymatic breakdown of collagen-based membranes and greater structural stability of synthetic polymer scaffolds. Strengths of this study include the standardized evaluation across multiple biologically relevant solutions and the combined quantitative and qualitative assessment using weight, thickness, and SEM analyses.

Fig20: Intact Collagen (Left) and PCL (Right) at the beginning of the study.

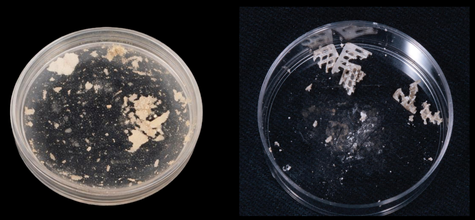


Fig21: Collagen (Left) and PCL (Right) end-point image showing extensive enzyme-induced membrane degradation.

Limitations include the in-vitro design, which does not fully reproduce in-vivo biological and mechanical conditions, and the lack of assessment of clinical handling and host response. Future investigations should incorporate in-vivo and clinical studies to evaluate regenerative outcomes, biocompatibility, and long-term performance of PCL/β-TCP scaffolds in guided bone regeneration.

LOMA LINDA UNIVERSITY
School of Dentistry

Biodegradable Polycaprolactone (PCL) Membrane for Bone Augmentation: A Comparative In Vitro Analysis of 3D Printed Scaffolds

Saud. S. Alajmi, Jaime Lozada, Aladdin Al Ardah, Joseph Lee, Zhe. Zhong, Ekaterina Zernitckaia

Academy of Osseointegration

Conclusion

Within the limitations of this in-vitro study, collagen membranes demonstrated rapid degradation, whereas the PCL/β-TCP scaffold showed a more controlled and gradual degradation profile. These findings suggest that membrane selection for guided bone regeneration should consider the required duration of barrier function and defect characteristics, and that further clinical studies are needed to confirm their relevance in vivo

Acknowledgements

This study was supported by the Loma Linda University School of Dentistry Student Research Program and the Implant Department through the Dr. Robert James Fund.

References