Detergent-free supercritical CO_2–assisted protocol for the production of sustainable and highly preserved decellularized porcine meniscus for orthopedic applications

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Meniscus injuries, along with the frequently ensuing condition of osteoarthritis, present a significant burden to the healthcare system [1]. While current treatments such as conservative management aim to alleviate symptoms and surgical approaches—including meniscectomy, meniscus repair, and allograft transplantation—strive for recovery, these interventions often result in suboptimal outcomes, failing to achieve complete and effective meniscal restoration [2]. Meniscus tissue engineering has emerged as a promising alternative, addressing these limitations by focusing on regenerative solutions.

This study aims to develop a decellularized scaffold derived from porcine meniscus—an abundant byproduct of daily meat consumption—to restore both the structure and function of the meniscus, thereby promoting long-term recovery. Porcine meniscus undergoes decellularization, a process designed to remove xenogeneic cellular components while preserving the essential extracellular matrix (ECM) [3]. Unlike conventional protocols that rely on harsh detergents, this study employs an innovative detergent-free decellularization approach utilizing a supercritical carbon dioxide ($scCO_2$)-assisted process. This protocol is environmentally friendly, fast-setting, and cost-effective, offering a significant improvement in sustainability and scalability over traditional methods. The optimized detergent-free protocol demonstrates remarkable efficacy, achieving residual DNA content below 50 ng/mg of dry tissue. Furthermore, it ensures the preservation of ECM matrix architecture and key components including collagen, elastin, and glycosaminoglycans, while maintaining biomechanical performance. *In vitro* cytotoxicity assays revealed no cytotoxicity after direct contact with human fibroblasts.

This innovative detergent-free decellularization process can open new horizons in terms of producing biomimetic meniscus scaffolds that can be further adapted for patient-specific regenerative applications through recellularization using patient-derived cells. Moreover, the decellularized porcine meniscus can be utilized as raw material in various meniscus tissue engineering approaches, such as 3D printing and hydrogels, expanding its potential for restoring and regenerating meniscal injuries.

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