Abstract

An important worldwide health concern is bone abnormalities, which can be caused by ageing, illness, or sports-related accidents. In order to address these problems, bone tissue engineering is a novel, interdisciplinary strategy that aims to improve patients' quality of life and heal bone abnormalities. Scaffolds are essential to this method because they function as three-dimensional (3D) structures that guide cell adhesion during the formation of bone tissue. Scaffold performance is greatly influenced by variables such as mechanical strength, physicochemical properties, and pore size. Porous bone scaffolds are made using a variety of methods, but 3D printing technology is drawing a lot of attention because of its potential to completely change the manufacturing industry. Benefits from this process include fast prototyping, flexible design, waste reduction, customisation at scale and economical manufacture of complex structures. Otolaryngology/maxillofacial surgery and dentistry are two medical specialities where 3D printing has had a revolutionary effect.

Among the various materials that can be used in 3D printing, polymers are undoubtedly the most versatile. Although polymer materials provide mechanical performance concerns, they have solved certain cost challenges. Porous scaffolds for bone tissue engineering have been produced by several industrial 3D printers during the past ten years. A rising number of articles have compared the growth of 3D printing to the third industrial revolution.

Because it is lightweight and inexpensive, polycaprolactone (PCL) is often utilised as polymer materials for tissue engineering scaffolds, in particular, thanks to its biodegradability and biocompatibility, it could be used as bone substitute in regenerative medicine. Our current study has focused on identifying and evaluating several PCL-based polymer blends for use in the creation of 3D scaffolds. Toughening ceramic fillers like Alumina toughened zirconia (ATZ) and fillers with distinguishing properties, including silica-based bioactive glasses with and without copper (SBA3/SBA3_Cu), have been used in these formulations. Adipose Tissue-Derived Stem Cells (ASC52 hTERT), Dermal Microvascular Endothelial Cells (HMEC-1), palatal fibroblasts (PF), epithelial cell (SG), have been used to evaluate the biological response to the different compounds.

Samples were studied to test biocompatibility using viability tests with an illuminometer, adhesion and spreading tests using a fluorescence microscopy. From a material perspective, surface morphology was studied using SEM and mechanical properties were investigated using a dynamometer.

For the PCL/SBA3 and PCL/SBA3_Cu systems, incorporating bioactive glass improved the scaffolds' physicochemical and biological properties without compromising flexibility. Copper-doped SBA3 enhanced endothelial cell proliferation through the release of angiogenic ions, while undoped SBA3 promoted mesenchymal stem cell growth, highlighting the potential of these composites for simultaneous bone and vessel formation. Future studies should focus on 3D scaffolds under dynamic culture to identify the optimal composition and assess long-term osteogenic and angiogenic effects, followed by in vivo validation.

For the PCL/ATZ composites, two mixing techniques solvent casting and impact milling were compared. Solvent casting produced better mechanical and biological results, particularly for PCL/ATZ 80/20, which showed high cell proliferation and balanced properties. In contrast, dry mixing caused polymer degradation and poorer performance. Notably, PCL/ATZ 80/20 also exhibited

strong potential for dental applications, improving epithelial and fibroblast adhesion, thus supporting its use in enhancing the mucosal seal of dental implants.

Overall, this work demonstrated that by combining polymers with bioactive or ceramic fillers and optimizing processing, it is possible to create multifunctional composite biomaterials tailored for both bone tissue regeneration.