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Preparation of a 3-D Printable Radiopaque Polymer Using Zirconium Oxide Nanomaterial

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Abstract

A joint dislocation is the complete displacement of a bone from its normal joint position. Joint dislocations constitute a small (3.6%) but critical portion of all athletic injuries in the sports world [1]. At the scene of joint dislocation injuries, certified athletic trainers (ATs) or physicians should be prepared for immediate on-site injury examination and closed joint reduction of the dislocated joint. In the United States, over 50,000 professional athletic trainers are working in the industry, and thousands of students require the skills to treat joint dislocations effectively [2]. Joint simulation models have long been accepted as a successful learning procedure to train AT professionals and physicians [3]. However, commercially available models are rare and expensive. Current shoulder dislocation models, for example, cost approximately $2,500 or more. There is a demand for affordable joint dislocation models that can be used in ATs and clinician training, particularly considering the AT programs are typically small with limited budgets for expensive instruments.

The three-dimensional (3D) printing technique, known as additive manufacturing (AM), has emerged as a transformative and effective tool for biomedical device fabrication at low cost. Various 3D printed medical devices have been developed by researchers, including drug delivery devices, tissue and organs for regenerative medicine, and medical simulators and models [4]. In recent years, there has been an increasing interest in producing medical simulators and models using the AM technique in sports health education, such as physician and athletic training. These 3D-printed patient-specific models with anatomical fidelity enable learners to practice before further medical intervention.

One major limitation in 3D printing materials is that the polymers (such as PLA, ABA) are not visible under X-ray imaging tools, the most common non-invasive clinical diagnosis and assessment methods for joint dislocation injuries. Radiopaque materials (radiopacifies) are required to enable the observation of the models to be visualized under X-ray imaging. Chemical compounds containing such as barium sulfate, zirconia, or iodine-based organic molecules are commonly radiopacified. Among them, Zirconia would be advantageous to use due to its high strength and resistance, as well as the highest radiopacity values among ceramics [5].

In this study, a 3D printable radiopaque polymer composite was prepared. The polymer was prepared by blending zirconia nanoparticles with fine polylactic acid (PLA) particles under different weight ratios. A scanning electron microscope confirmed the zirconia particles ranging from 500 nm to 1000 nm, and the PLA particles ranging from 0.50 nm to 300 nm, respectively. The polymer composites were then extruded to prepare filament through a Filabot's EX2 Filament Extruder. Various extruding conditions including extruding temperature, speeding, and cooling temperatures, were optimized to prepare the filament. The mechanical properties of the filaments were further evaluated through tensile testing, using an MTI-10k machine. The initial results showed that the PLA mixed with zirconium oxide filament had a higher maximum load, average elastic modulus, and ultimate strength than the PLA filament. However, the PLA zirconium oxide filament displayed a relative shorter average percentage of elongation. A medical model for joint dislocation were developed and evaluated under an X-ray and microcomputed tomography imaging.

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