

# CHAPTER I

## INTRODUCTION

### 1.1 Background

A phantom is a model used to simulate the physical and radiological properties of human tissue. Phantoms serve as testing media without involving living subjects directly, especially in calibrating tools, measuring radiation doses, and evaluating image quality in radiology and radiotherapy within medical physics (Podgorsak, 2016). Common materials used for phantoms include water, epoxy resin, and composite polymers due to their physical characteristics resembling human tissues. Epoxy resin is often used to simulate soft tissues in phantoms because its density and effective atomic number can be engineered to resemble human soft tissue (White & Pharoah, 2014). Additionally, epoxy resin provides excellent mechanical and chemical stability after curing, enabling it to maintain its physical properties for extended periods (ICRU, 1989). From a fabrication perspective, epoxy resin is relatively easy to mold and modify in composition, making it widely used in the production of radiology phantoms for dosimetry and medical imaging purposes. (Bushberg, 2012) However, conventional phantoms have limitations as they cannot mimic the biological functions of tissues, and their production costs are relatively high. Therefore, more cost-effective and adaptable alternatives are needed (Moura, 2020).

Previous research has shown that porosity and density are crucial factors. In medical physics, one essential aspect of phantom development is matching the material characteristics to human bone tissue. Human bone density ranges from 1,8–2,0 g/cm<sup>3</sup> and porosity varies between 4–10%, depending on bone type and age (Currey, 1983). These values serve as references for determining the materials used in bone phantoms to ensure they mimic the mechanical and radiological responses of natural bone. Thus, research on bone phantoms focuses on finding economical and easily accessible materials while maintaining the appropriate physical and radiological properties. Chicken eggshells were selected as the primary material for the arm bone phantom model in this study due to their high calcium carbonate (CaCO<sub>3</sub>) content, ranging from 94-96%, which is chemically similar to the mineral content of human bones, such as hydroxyapatite (Owuamanam, 2021). Furthermore, previous studies on Bio-Epoxy Eggshell Composites reported that composites made from chicken eggshell powder and epoxy resin matrix have better bending and tensile strength than pure epoxy resin while maintaining the crystallinity of

the calcite filler in  $\text{CaCO}_3$  (Owuamanam, 2021). Previous research also shows that phantoms made from economical materials including eggshells can simulate the density and composition of bone minerals, so they are suitable for quality assurance of X-ray imaging and educational purposes. (Alkhateeb, 2019).

The selection of materials such as epoxy resin, chicken eggshells, and  $\text{CaCO}_3$  is based on their similarity in physical and radiological properties to human bone tissue. Epoxy resin serves as a stable binding matrix, while eggshells and  $\text{CaCO}_3$  act as mineral fillers to enhance density and radiation attenuation capability (Owuamanam, 2021); (Alkhateeb, 2019). his study uses silicone molds with epoxy resin to form arm bones according to anatomy. The testing includes physical and material tests, where the physical test is conducted to determine the dimensions, length, volume, and diameter of the arm bone using calipers. Meanwhile, the material test begins with density testing using the Archimedes method thru the measurement of dry mass, saturated mass, and submerged mass to accurately determine the material's density. The testing is then continued with the determination of porosity, which also uses the Archimedes principle, allowing the internal cavity value of the material to be calculated from the difference of the three masses. After that, XRF analysis was conducted, in previous research aimed at validating that the phantom material has a composition similar to human bone, making it relevant for radiology and dosimetry applications. Where the characterization results in previous research showed that the egg shell is dominated by calcium (Ca) and contains O, C, and traces of Mg, Sr, and P, confirming the presence of calcite mineral ( $\text{CaCO}_3$ ) as the main component (Rani, 2024).

So far, most research has focused on the creation of thorax phantoms for radiation calibration, while the development of arm bone phantoms according to ISO 4037-3:2019 standards is still very limited, and the absence of bone models in radiological arm phantoms serves as the background for this research. This research gap arises because most conventional arm bone phantoms have not utilized natural biocomposites as the main material, resulting in density, porosity, and mechanical response properties that do not fully resemble the characteristics of real bone. Furthermore, the design used in this study differs from the general design of arm bone phantoms. an evaluation of the suitability of the chicken egg shell composite phantom against the ISO 4037-3:2019 standard is necessary

to determine whether the changes in material and design can meet the requirements needed for medical and engineering testing applications. The performance of a phantom is greatly influenced by its density, radiation attenuation capabilities such as linear and mass attenuation coefficients, and its microstructural characteristics, including chemical composition and the level of homogeneity resembling human soft tissue and bone (Sandborg, 1990). Therefore, this research was conducted to modify and validate the Eggshell-based Arm Bone Phantom as a bone model according to the ISO 4037-3:2019 standard. The objective of this research is to determine the compatibility of the composite material characteristics with the aforementioned standard and to ensure the phantom's ability to accurately represent the human bone structure. This research is expected to provide benefits both academically and practically. Academically, this research enriches the literature on the potential use of eggshell waste as an alternative material in the development of radiological phantoms. Practically, the results of this research are expected to demonstrate the potential of an eggshell resin composite to resemble human bone tissue and can be used as an affordable learning medium or a reliable tool for radiation-based measurements. In addition, the utilization of eggshell waste directly supports environmental sustainability through organic waste reduction. By optimizing the composite formulation, the fabricated arm bone phantom successfully mimics the density, porosity, and radiological characteristics required for standard bone models. XRF analysis also confirms that the inclusion of bone-related mineral elements ensures its microstructural and radiological suitability as a high-fidelity bone phantom..

## **1.2 Problem Formulation**

Based on the background presented, the problems addressed in this research can be formulated as follows::

1. How is the process of creating a bone model for the arm using chicken eggshell composite as the bone model?
2. How do the validation results of the phantom design compare regarding its dimensions, volume, and geometric characteristics against the ISO 4037-3:2019 standard?
3. What are the characteristics of the chicken eggshell composite material used as a bone model in terms of porosity, density, and XRF how do these characteristics compare with human bone tissue?

### **1.3 Research Objectives**

The objectives of this study are as follows:

1. To determine the process of creating an arm phantom using chicken eggshell composite as a bone.
2. To validate the design of the bone phantom by comparing its dimensions, volume, and geometric characteristics against the ISO 4037-3:2019 standard.
3. To analyze and evaluate the characteristics of the chicken eggshell composite material used as a bone model, specifically in terms of porosity, density, and XRF to human bone tissue characteristic.

### **1.4 Research Benefits**

This research is expected to provide several benefits as outlined below:

1. Academic Benefits
  - a. To enhance scientific knowledge regarding the use of natural materials, particularly chicken eggshells as a source of calcium carbonate ( $\text{CaCO}_3$ ), in the development of radiology phantoms.
  - b. To serve as a scientific reference for the physical and material characterization of composites, such as density and porosity, in phantom materials.
  - c. To provide a foundation for future research on the development of phantoms for other body parts based on the ISO 4037-3:2019 standard.
2. Practical Benefits
  - a. To produce a bone phantom model that closely resembles human bone characteristics, both physically and radiologically.
  - b. To be used for educational purposes, training, dosimetry research, and radiological instrument calibration.
3. Environmental Benefits
  - a. To utilize chicken eggshell waste as a valuable, environmentally friendly material, thus reducing organic waste.
  - b. To encourage sustainable research by using locally sourced, eco-friendly materials.

### **1.5 Research limitations**

To maintain the focus of this study and ensure that the research objectives are achieved, the scope of this research is limited as follows:

1. This study focuses only on investigating the potential of a chicken eggshell resin composite as a material for a humerus bone phantom model.
2. The phantom developed in this study is limited to the humerus bone and does not include other anatomical structures such as the radius, ulna, soft tissues, muscles, or skin.
3. The material characterization is limited to the evaluation of density, porosity, and elemental composition using X-ray fluorescence (XRF).
4. The phantom design validation is restricted to the assessment of its dimensions, volume, and geometric characteristics in comparison with the requirements of ISO 4037-3:2019.
5. This study does not include radiological performance evaluations, such as Hounsfield Unit (HU) measurement, linear or mass attenuation coefficient determination, image quality assessment, or radiation dose measurement.
6. The materials used in this study are limited to chicken eggshell powder, epoxy resin, and calcium carbonate ( $\text{CaCO}_3$ ) based on the selected composite formulations.
7. The findings of this study are intended to evaluate the potential of the developed composite as a humerus bone phantom material. Therefore, the phantom cannot yet be considered fully equivalent to human bone without further radiological performance testing.