Helmholtz coils model as pulsed electromagnetic field therapy devices for fracture healing using comsol multiphysics

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Abstract. The World Health Organization in 2009 recorded that more than a million people died due to accidents, and about 2 million people had physical accidents, namely fractures. The main challenge for clinicians today is finding an effective and inexpensive method of fracture healing. In this case, a pulsed electromagnetic field (PEMF) can be used, which is a non-invasive technique that induces and generates a magnetic field due to changes in the electric field. So this research aims to create a simulation design of PEMF therapy device for fracture healing. The stages of this research method are to make Helmholtz coil modelling of PEMF therapy device using Comsol Multiphysics with variations in the number of turns, the distance between two coils, voltage or current, and coil diameter, to obtain the correct magnetic field value to accelerate fracture healing. The result of this research is the successful design of a PEMF device that produces a magnetic field value $B = 1.5$ mT on the number of turns $N = 150$, the distance between two coils $r = 2.5$ cm, the current value $I = 0.5$ A, and coil diameter $D = 5$ cm.

1. Introduction
Fracture is a crack in the continuity of the bone and the severity is determined according to its type and width [1][2]. The World Health Organization in 2009 reported that more than a million people died due to accidents, and about two million people had physical accidents, namely fractures. Fracture surgery is an invasive procedure by making an incision and closing the incision wound with sutures [3]. Fracture surgery can cause problems in the impediment of physical mobility as well as postsurgical pain disorder [4]. The main challenge for clinicians today is finding a method of healing fracture non-union and preventing the delayed union from occurring effectively and inexpensively. A pulsed electromagnetic field (PEMF) can offer a solution to this problem. It is a non-invasive technique that induces and generates a magnetic field due to a change in the electric field [5].

PEMF has been studied for a long time both in vitro (cell research), pre-clinical (experimental animal studies), and clinical scales, by providing a physical stimulus in the form of PEMF exposure (1.5 mT, 75 Hz) for 28 days during the period of bone cell differentiation. It was found that there was an increase in the levels of Alkaline phosphatase (ALP) and Osteocalcin (OCL), which are markers of bone formation (osteogenesis) [6]. In order to researchers design the PEMF tool using Helmholtz coils and identify the parameters needed to generate a magnetic field of 1.5 mT, such as the radius of the Helmholtz roll, the variation of current, and the variation of current and voltage, it is necessary to model the magnetic field as a reference device to determine the value of several measurement variables or the process of conducting the experiment.
2. Methods
The simulation method was carried out using COMSOL version 5.4 [7]. The results showed the field pattern and magnetic field strength generated by the Helmholtz coil. The characteristics used were coil diameter, number of turns, current flow, and distance between Helmholtz coils. According to Helmholtz equation as follows [8].

\[ B = \frac{\mu_0 N I R^2}{2 (R^2 + Z^2)^{3/2}} \]  

(1)

![Figure 1. Model Helmholtz Coils](image)

The Helmholtz coils model is shown in Figure 1. This model consists of two coils with a diameter \( D \), the distance between two coils is \( r \), each coil consisting of several turns of copper wire with a current \( I \). Afterwards, given the variation in the number of turns, coil diameter, the distance between the coils, and electrical current to generate a magnetic field of 1.5 mT between the two Helmholtz coils.

3. Results and discussion
Helmholtz coils modelling has been performed using COMSOL application version 5.4. The results displayed are the magnetic field pattern and magnetic field strength generated by Helmholtz coils, as shown in Figure 2. The characteristics used are the diameter of the coil, the number of turns, and the distance between Helmholtz coils and the current. The highest magnetic field \( B \) value was 1.5 mT. This result was obtained from the entered parameters, a number of turns \( N \) is 150, of the distance between two coils \( r \) is 2.5 cm, current \( I \) is 0.5 A, and diameter of coil \( D \) is 5 cm. The parameter values were entered repeatedly until the magnetic field value was 1.5 mT [6].

Variation of the parameters was performed to observe the relationship between the parameters and the magnetic field. From the variation in the number of turns are 100, 200, 300, 400 and 500 at \( r \) is 5 cm, \( I \) is 0.5 A, and \( D \) is 10 cm, the resulting magnetic field \( B \) was 1.2 mT, 2.5 mT, 3.5 mT, 4.7 mT, and 6 mT. It is shown in Figure 3. The increasing number of turn produced the higher of the magnetic field. This is in accordance with the Helmholtz equation [8].

Figure 4 shows that the greater of the distance between the coils produced smaller the magnetic field. The values of magnetic field \( B \) were 1.2 mT, 0.47 mT, 0.21 mT, 0.1 mT, and 0.053 mT. These results came from variations in the distance between the coils are 5 cm, 10 cm, 15 cm, 20 cm and 25 cm at \( N \) is 100, \( I \) is 0.5 A, and \( D \) is 100 cm.

The values of magnetic field \( B \) were 1.2 mT, 2.5 mT, 3.5 mT, 4.7 mT, and 6 mT. It was obtained from the variation of currents are 0.5 A, 1 A, 1.5 A, 2 A, and 2.5 A at \( N \) is 100, \( r \) is 5 cm, and \( D \) is 10
cm. The result shows in Figure 5. The greater of current value produced the greater of magnetic field. This is in accordance with the Helmholtz equation [8].

![Figure 2. Distribution magnetic field between Helmholtz coils](image)

![Figure 3. The magnetic field with variation number of turns](image)

![Figure 4. The magnetic field with the variation of distance between the coils](image)
Figure 5. The magnetic field with variation electric current

Figure 6 shows that the greater of coil diameter produced, the smaller of the magnetic field. The variation of the coil diameter are 10 cm, 20 cm, 30 cm, 40 cm and 50 cm at $N$ is 100, $r$ is 5 cm, and $I = 0.5 \, \text{A}$ produced magnetic field are 1.2 mT, 1.1 mT, 1 mT, 1 mT, and 0.9 mT. This is in accordance with the Helmholtz equation [8].

Figure 6. The magnetic field with variation diameter coils

4. Conclusion
The number of turns and the amount of electrical current are proportional to the value of the magnetic field, while the distance between the coils and the diameter of the coils are inversely proportional to the value of the magnetic field. This research succeeded in designing a PEMF device that produces a magnetic field value $B$ is 1.5 mT on the number of turns $N$ is 150, distance between two coils $r$ is 2.5 cm, the current value $I$ is 0.5 A, and coil diameter $D$ is 5 cm.

Acknowledgement
Thanks to the Faculty of Mathematics and Natural Sciences, Tadulako University, through the Superior Research Grant (Hibah Penelitian Unggulan DIPA FMIPA UNTAD) who has funded this research so that this research has been conducted smoothly.

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