Development of Magnetic Induction Spectroscopy Technique for Internal Fixator Screw Self-Loosening Detection

by

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LIST OF ABBREVIATIONS

MIS	Magnetic Induction Spectroscopy
MIT	Magnetic Induction Tomography
EMAT	Electromagnetic Acoustic Transducer
MF	Magnetic Field
EM	Electromagnetic
T_x	Transmitter
R_x	Receiver
3D	Three Dimensional
2D	Two Dimensional
NDT	Non-Destructive Testing
NDE	Non-Destructive Examination
NDI	Non-Destructive Inspection
PEP	Passive Electrical Properties
RF	Radio Frequency
Hz	Hertz
KHz	Kilohertz
MHz	Megahertz
FEA	Finite Element Analysis
PPM	Periodic Permanent Magnet
pH	The Power of Hydrogen
AC	Alternate Current
VEPS	Volumetric Electromagnetic Phase-Shift Spectroscopy
MRI	Magnetic Resonance Imaging
CT	Computer Tomography
USPV	Ultrasonic Pulse Velocity

LIST OF SYMBOLS

∇	Divergence
D	Electric Flux Density
B	Magnetic Flux Densities
ρ	Volume of Charge Density
E	Electric Field
H	Magnetic Field
σ	Conductivity
ε	Permittivity
μ	Permeability
ω	Angular Frequency
f	Frequency
ε_r	Relative Permittivity
ε_0	Permittivity of Free Space
α	Alpha
β	Beta
γ	Gamma
I	Current

Pembangunan Teknik Spektroskopi Aruhan Magnet Untuk Pengesanan Skru Penetap Dalaman Longgar-Sendiri

ABSTRAK

Keretakan tulang manusia menyebabkan kesakitan dan kesakitan refleks yang melibatkan tulang dan tisu di sekelilingnya. Penetapan keretakan dikenali sebagai implan tulang yang digunakan dalam proses penyembuhan tulang yang patah dan retak. Secara klinikal penetapan tulang yang retak adalah untuk menstabilkan tulang patah, mempercepat proses penyembuhan tulang yang cedera, dan memulihkan pergerakan dan fungsi penuh dari kecederaan yang melampau. Selepas fasa pemulihan, terdapat gangguan serta trauma dan tindakbalas pergerakan, yang menyebabkan kegagalan implan. Skru longgar sendiri dalam penetapan dalaman adalah jenis kegagalan implan yang disebabkan oleh beberapa parameter seperti dimensi dan bentuk plat, pemisahan antara pemasangan skru, kepegalan plat dan skru, peredaman di sekeliling tisu dan fleksibiliti kawasan retak. Kajian ini bertujuan membangunkan kaedah pengukuran yang dinamik untuk menganalisis mekanisma skru longgar sendiri. Kelonggaran skru implan disebabkan oleh pelonggaran septik dan aseptik. Kajian ini memfokuskan pada pelonggaran aseptik sebagai analisis kerja yang disebabkan oleh jurang mikro antara skru dan antara muka tulang.Sekiranya skru longgar dapat dikesan pada tahap awal penetapan, risiko operasi pembedahan semula dapat dikurangkan dengan teknik bukan invasif. Objektif utama penyelidikan ini untuk membangunkan pengesanan skru longgar sendiri untuk penetapan dalaman menggunakan kaedah elektromagnetik. Elektromagnetik boleh diinduksi dalam skru dengan bahan daripada ferromagnetik di mana sensor berada di sekitar tapak keretakan. Kekuatan medan diperlukan untuk mempengaruhi skru, kebolehtelapan di tisu sekeliling dan pemisahan antara skru dan sensor. Model pembangunan unsur terhingga pada tulang dan implan dilaksanakan dengan integrasi Spektroskopi Induksi Magnetik (MIS) dengan elektromagnetik. Saluran tunggal induksi magnetik dengan satu pemancar dan satu penerima dan masing-masing dibekalkan arus 1A dan 0.5A. Medan induksi yang dijanakan pada frekuensi 1 MHz hingga 10 MHz dari pemancar digunakan untuk menembusi tulang dan implan, dan diterima di penerima. Bahan skru yang digunakan di dalam kajian ini diperbuat oleh keluli tahan karat yang menjadi bahan ferromagnet dan ia bertindak balas dengan lebih baik kepada medan magnet. Teknik MIS digunakan untuk pelbagai model implan tulang adalah untuk membezakan perubahan jumlah isyarat yang diterima. Proses simulasi kajian ini dilakukan dalam perisian COMSOL Multiphysics versi 5.2a. Simulasi dimulakan dengan menyiasat reaksi medan magnet dengan tisu biologi. Analisis kami menunjukkan medan magnet berubah apabila terangsang melalui sifat elektrik pasif (PEP) tisu biologi yang berbeza. Analisis utama menunjukkan korelasi kuat antara model jurang antara muka implan tulang (BIGI) dengan jumlah isyarat medan magnet. Hasil medan magnet menunjukkan nilai yang berbeza untuk setiap kekonduksian dan permitiviti yang dikesan dari penerima untuk setiap model BIGI. Kelonggaran skru dianalisis berdasarkan medan magnet dengan menunjukkan julat kelonggaran berlaku di atas 100um celah mikro kerana ketegangan yang tinggi dalam antara muka skru dan tulang. Oleh itu sistem MIS dapat mengesan kelonggaran sendiri skru penetapan dalaman dengan frekuensi 10MHz sebagai frekuensi operasi.

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ABSTRACT

Fracture in human bone leads to a pain and reflex injury involving bone and surrounding tissues. Fracture fixation known as bone implants used in healing process of bone fracture and crack. The clinically fixation is used to stabilize the fractured bone, to enable fast healing of the injured bone, and to return early mobility and full function of the injured extremity. After repair phase, there are disturbance as well as pain and reflex immobilization, therefore cause the implant failure. Screw self-loosening of internal fixator is a type of implant failure which is caused by a number of parameters such as dimensions and shape of the plate, separation between screw fittings, stiffness of the plate and screws, damping nature of the surrounding tissue and flexibility of the fracture site. This study aims to develop a dynamic measurement method to analyse screw self-loosening mechanism. Loosening of screw implant is caused by septic and aseptic loosening. This studies focus on aseptic loosening as a work analysis which caused by the micro gap between the screw and bone interface. If the screw loosening can be detected at early stage of fixation, the risk of re-surgical operation can be reduced. This study involved the development of a non-invasive technique for detecting screw self-loosening in internal fixation. The main objective of this research is to investigate the screw self-loosening detection for internal fixation using the electromagnetic method. An electromagnetic can be induced in a ferromagnetic screw material where the sensor positioned over the fracture site. The strength of the field is necessary to excite the screw, the conductivity and permittivity of the surrounding tissue and the separation between the screw and the sensor. Finite element development model for bone and implant is executed with the integration of Magnetic Induction Spectroscopy (MIS) and electromagnetic based approached. Single channel magnetic induction with one transmitter and one receiver with supplied current of 1A and 0.5A is employed. The induction field was generated at frequency of 1 MHz to 10 MHz from transmitter used to penetrate into the bone and implant, which then received at the receiver. The screw material is made by stainless steel which a hard ferromagnetic material, thus it respond better to a rapidly varying magnetic field than a soft material. The MIS technique was applied to various model of bone implant to differentiate the received total signal changed. The simulation process of this study was executed in COMSOL Multiphysics version 5.2a software. The simulation initiated by investigating magnetic field reaction with biological tissues. Our analysis shows the magnetic field changes when excites through different passive electrical properties (PEP) of biological tissues. The main analysis shows a strong correlation between bone implant gap interfaces (BIGI) model with the total signal of magnetic field. The magnetic field result shows the different value for each conductivity and permittivity detected from the receiver for each BIGI model. The loosening of screw was analysed based on the magnetic field by indicates the range of loosening occur above 100um of microgap due to high strains in the screw and bone interface. Thus MIS system was able in detecting screw-self loosening of internal fixation with 10MHz frequency as an operating frequency.

CHAPTER 1 : INTRODUCTION

1.1 Research Background

Every fracture results in a complex tissue injuries involving bone and the soft tissues that surround it. Local circulatory abnormalities and symptoms of local inflammation, as well as pain and reflex immobilization, occur immediately after the fracture and during healing period (Willenegger, 1992). A guiding principle of fracture care is important to ensure better healing of bone fracture. Fracture fixation is a bone implant, which used in healing process of bone fracture and crack. The primary goal of fracture fixation is to stabilise the broken bone, allow for rapid healing of the soft tissues and also restore early mobility and complete function of the injured extremity (Taljanovic et al., 2003).

Bone implant divided into two types which are external fixation and internal fixation. These two types of fixation is medically fixed based on the condition of bone fractures occurred. Generally, bone implants are combination of plates and screws or screws only which will be attached to support the bone crack to promote the healing process of the bone. The concept of fracture healing can divided into two types which are primary fracture healing and secondary fracture healing. Primary fracture healing referred to osteonal healing occurred when anatomically of fractures is reduced which needs high stability. While, secondary healing fractures occurs when a larger a mass of callus is created (Phillips, 2005). The goal for fracture fixation is to ensure the bone fracture is union and aside from that for early motion following surgery (Miller, 2007).

The failure of bone implant may occurs because of overloading, sports, accident and etc. In particular, implant failure remains a problem for unstable fractures, despite improved techniques and various implant modifications (Z. Gao et al., 2018). Clinically, implant failure may be defined as a failure of implantation procedure to produce satisfactory results. For early detection of loosening and confirmation of the necessity for surgical intervention, a precise diagnosis of implant fixation is required. However, current imaging method are not well establish to determine this early detection. There are several different techniques have been proposed for non-destructive evaluation of materials and technical components detection which is the electromagnetic method. However, there are limited amount of study to develop the technique in bone fracture that initiated by self-loosening of internal fixator screw under mixed mode loading condition (Perren, 2014).

A clinical approached have been made in order to reduce the pain by the patient when the implant failed to stabilize the bone. As mentioned in Andreykiv et al., (2012), the study was made to stabilize hip stems loosening using cement injection into osteolytic cavities. A patient who cannot undergo standard revision surgery was bringing into re-fixation of loose hip implants technique by applying cement injection osteolytic areas around the cement mantle. The improvement in walking distance, pain relief and patient's independence proves the preliminary clinical result of this technique. However, this approach does not solve the screw loosening well in the fracture fixation because this approach focus on stabilizing the implant rather than detects the implant loosening.

Kar., et al (2016) have made a study on failure analysis of titanium screw which used in RASL (reduction and association of the scaphoid and lunate bones) procedure. This study investigate the failure of screw implant after one month of surgery. The analysis observed that there are complete fracture of the screw around the screw thread which causing tapered thread at possible location from the back of the screw towards the front of the screw. By using fractographic analysis, the screw thread show a significant fretting and flattening. These fretting and flattening of screw thread leads to micro motion to the screw and reduce the rigid support between the screw and bone interface. Because of interacting factors such as a reverse bending fatigue inside the tapered to flute transition zone, lack of fixation between the bone and the screw, micro motion of the screw threads against the bone. Then, the fracture morphology shows that premature failure occurred. Furthermore, inappropriate screw diameter or improper installation torque during surgical installation might be exacerbated the premature failure condition. Figure 1.1 shows the 3 close-up view for three cases of implant failure.

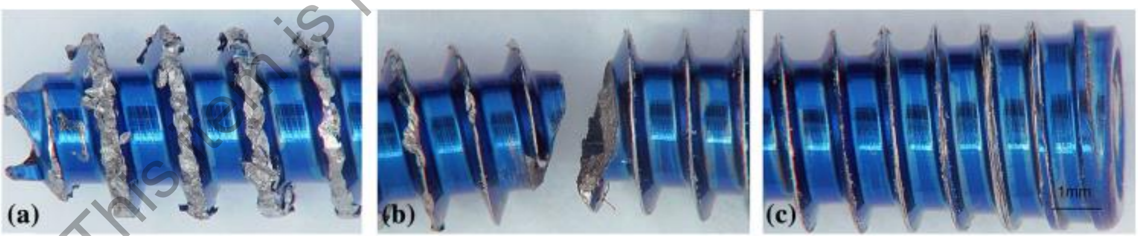

Figure 1.1 (a) Thread flattening flute screw, (b) fracture occurred caused taper and flute transition, (c) tapered region on screw (Kar et al., 2016).

Magnetic Induction Spectroscopy (MIS) will be the focusing technique will be used in this study by applying multi-frequency. All the concept is designed and simulated using COMSOL Multiphysics 5.2a simulation software. Solidworks is used to design the geometries of bone and screw to simulate be in simulation software with the electromagnetic parts. The system consist of two essential parts which are transmitter and receiver as working electromagnetic based. This system works as a single channel measurement which applied the magnetic induction phenomena.

1.2 Problem Statement

Screw self-loosening of internal fixator is caused by a number of parameters such as dimensions and shape of the plate, which screws are loose, the extent of loosening, separation between screw fittings, stiffness of the plate and screws, damping nature of the surrounding tissue and flexibility of the fracture site. Problems that occurred after insertion can cause infection at the fracture site, which cause the screw loose. The important role of time and adequate treatment especially screw design must be played in order achieving precise diagnosis of loosening of the implant fixation. However, today's diagnostic tools, the result of study showed still not satisfy mainly on radiological evaluation (Ruther et al., 2013). Variety of implant design and quality are developed and improved to restore anatomy and enhance healing process of fractured bone but at times, implants fail to achieve desired out come in few cases and a repeated surgery is required (Sunil Kumar et al., 2014). From previous research, screw or bolt loosening in mechanical engineering is a common problem. Several methods have been developed to detect the screw fastening or bolt loosening. (Spirig et al., 2019) have made a study on screw loosening using radiograph, computed tomography and magnetic resonance imaging, but the result indicate that none of the modalities are sufficiently sensitive in detecting screw loosening unless the computed tomography show the osteolysis of bone which prove the screw likely loose. However, to date, there is no established method to detect implant screw loosening for implant fixation. Therefore, a new approach to detect screw self-loosening of internal fixation is investigated using the electromagnetic method. The approach of magnetic induction spectroscopy (MIS) is used in this study. Further investigation of MIS has included the biological tissues and implant fixation assembly, which a huge challenges in applying MIS. The MIS needs a proper formulation specification of their transmitter and receiver coils to produce suitable of magnetic field around the fracture site to ensure the energy can absorb and penetrates into the biological tissues and implant fixation. This includes with the number of turns for coils, current applied for coils, frequency selection, diameter of coils and separation or gap between coils and fracture site. Thus, to realise the screw self-loosening between implant and bone required the complex formulation of MIS and electromagnetic theoretical knowledge using finite element approach.

1.3 Research Objectives

This study aims to investigate the effect of electromagnetic at installed screw internal fixation by developing magnetic induction spectroscopy (MIS) system to analyse the self-loosening screw in bone implant. Three objectives are outlined to be achieved as follows:

I. To develop the series of finite element (FE) model for screw and bone configuration based on magnetic induction signal approach.

II. To localize the screw implant under the realistic model simulation by using magnetic field.

III. To develop the magnetic induction phase shift technique for screw self-loosening detection in bone based on fixation stability.

1.4 Research Motivation

This section discusses the three factors that motivate the research undertaken in this study. First, to discover the benefit of electromagnetic method in medical field for fracture fixation of bone. Second, to identify the risk factors for implant failure at early stage, which can reduces cost of operation. Third, to support the broken bone, allow for rapid healing of the wounded bone, and to restore early mobility and complete function of the injured extremities, all of which can lessen patient's suffering.

The motivation arise due to difficulty in reducing the traumas to the patient during the fixation failures which contribute to new technique. These technique was tested in simulation along with human's biological tissues where the approach of using magnetic induction on soft and hard tissue can be develops by using a series of finite element (FE) model to study the behaviour of magnetic induction signal based on passive electrical properties (PEP) of biological tissues. The study of magnetic induction technique lead to new discovery on locating the screw which beneath the soft and hard tissue which being one of the contribution of this research. The major contribution of this research was determined by study the loosening of screw in bone by simulate a series of bone-implant gap model to identify the loosening. These contribution was done by simulate the objectives approach of this research.