A STUDY OF ACOUSTIC EMISSIONS SIGNAL EVENTS IN PEDICLE SCREW FIXATION PROCEDURE

MOHD HIZZUAN BIN HARUN

BACHELOR OF MECHANICAL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled “A Study of Acoustic Emissions Signal Events in Pedicle Screw Fixation Procedure” is written by Mohd Hizzuan Bin Harun. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

Examiner	Signature

A STUDY OF ACOUSTIC EMISSIONS SIGNAL EVENTS IN PEDICLE SCREW FIXATION PROCEDURE

MOHD HIZZUAN BIN HARUN

Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2009

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature

Name of Supervisor: MR MOHD HAFIZI BIN ZOHARI

Position: LECTURER

Date: NOVEMBER 2009

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
Name: MOHD HIZZUAN BIN HARUN
ID Number: MA06023
Date: NOVEMBER 2009

Dedicated to my beloved family and friends

ACKNOWLEDGEMENT

Alhamdulillah, all the greatest thanks and grateful just to Allah S.W.T for allowing and guiding me to conceptualize, develop and complete this study. Special appreciation and thanks to my very kind and generous project’s supervisor, Mr Mohd Hafizi Bin Zohari for your constant guidance, suggestions, advice and encouragement.

I would like to express my sincere appreciation to my friends and classmates for giving me a lot of information, suggestion and guidance for me to finish this thesis.

Great thanks to my parents, Harun Bin Awang and Rohimah Binti Abas for being great supporter and motivator. Without your prayer and blessing I do not believe I could finish this project successfully. Finally, I want to thank all people who involve directly or indirectly in this project. May Allah S.W.T bless us with triumph and goodness.

Jazakum Allahu khayran, and peace to all.

Mohd Hizzuan Bin Harun
UMP, 2009

ABSTRACT

The purpose of this study is to propose a safe and easy method to help medical practitioner for perforation of hole during pedicle screw fixation procedure by using acoustic emissions technique. Generally in Malaysia, the medical practitioner had a really hard time while doing the pedicle screw fixation procedure when it involved with cervical spine. The cervical spine is the most complicated articular system in the body. The pedicles of the cervical spine are short and thick and become the most critical part during the screw insertion process. For this study, two cervical bovine vertebras were used instead of human vertebrae. The source of the acoustic emissions (AE) signal events was from the breakthrough of the bone tissues and it is was captured using AE sensor with the help of Acoustic Emission Detector Software version 2.1.3. Acoustic emissions signal events showed the different trend in hits results when the signal run through the bone tissues either hard of spongy during the perforation of the bone. By the experiment on the first bone, there were sudden increase of hits occur that tell us the pedicle probe had been breakthrough the interface between the hard and soft bone tissues. Meanwhile, in the experiment on the second bone an indicator is used to estimate the time of penetration level where the crack propagation of the bone tissues interfaces occur and the result showed the time were vary for each hole.

ABSTRAK

Tujuan kajian ini dijalankan adalah untuk mencadangkan satu kaedah yang selamat dan mudah untuk membantu pengamal perubatan untuk tebukan lubang dalam prosedur pemasang skru di tulang “pedicle” menggunakan teknik pancaran akustik. Biasanya di Malaysia, pengamal perubatan akan menghadapi kesusahan ketika melakukan prosedur pemasangan skru di tulang “pedicle” apabila melibatkan tulang belakang serviks. Tulang belakang serviks adalah yang paling kompleks dalam sistem artikular badan. Tulang “pedicle” serviks adalah pendek dan tebal yang menjadikannya bahagian paling kritikal semasa proses kemasukan skru. Untuk kajian ini, sebanyak dua tulang belakang lembu digunakan berbanding tulang belakang manusia. Punca isyarat pacaran akustik (AE) aktiviti adalah daripada tisu-tisu tulang dan ianya dicerap dengan menggunakan penderia akustik dengan bantuan paparan dari perisian Acoustic Emission Detector Software versi 2.1.3. Aktiviti daripada pancaran akustik menunjukan pola yang berlainan dalam keputusan “hits” apabila pancaran melalui tisu-tisu tulang yang keras atau lembut semasa tebukan lubang dibuat. Dalam eksperimen di tulang pertama, terdapat peningkatan “hits” secara tiba-tiba berlaku memberitahu kita bahawa alat “pedicle” telah mencapai lapisan di antara tisu tulang yang keras atau lembut. Sementara itu, dalam eksperimen di tulang kedua, satu penanda digunakan untuk menganggar masa tahap tembusan dimana penyebaran keretakan pada lapisan tisu tulang berlaku dan keputusan masa yang ditunjukan adalah berbeza untuk setiap lubang.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Amplitude
D	Duration
Ey	Energy
k	Kurtosis
N	Counts
R	Rise time
t	Time
V_{rms}	Average voltage
V_{peak}	Peak amplitude
y	RMS
y_{rms}	RMS amplitude

LIST OF ABBREVIATIONS

AE	Acoustic emission
NDE	Non destructive evaluation
NDT	Non destructive testing
RMS	Root mean square

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **A STUDY OF ACOUSTIC EMISSIONS SIGNAL EVENTS IN PEDICLE SCREW FIXATION PROCEDURE**

SESI PENGAJIAN: 2009/2010

Saya **MOHD HIZZUAN BIN HARUN (860621-46-5477)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda/~~Sarjana~~ /~~Doktor Falsafah~~)* ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

[ ]	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
[√]	**TIDAK TERHAD**	

Disahkan oleh:

__________________________ (TANDATANGAN PENULIS)

__________________________ (TANDATANGAN PENYELIA)

Alamat Tetap:

NO 3142 KG TOK DAT KERANDANG
22000 JERTEH BESUT
TERENGGANU

EN MOHD HAFIZI BIN ZOHARI
(Nama Penyelia)

Tarikh: **30 NOVEMBER 2009**

Tarikh: : **30 NOVEMBER 2009**

CATATAN:
* Potong yang tidak berkenaan.
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai atau TERHAD.
♦ Tesis dimaksudkan sebagai tesis bagi Ijazah doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

In medical practices, bone drilling process is one of the processes that need to be master by physicians especially by orthopedic surgeon. In orthopedic surgery always involved the musculoskeletal system and surgeon need to use both surgical and non-surgical means to treat musculoskeletal trauma, sports injuries, degenerative diseases, infections, tumors and congenital conditions. Besides, the need of bone drilling process is also important in treating the bone fracture.

Before this, bone drilling tools used in surgery do not include any means for the control of penetration and it totally depend on surgeon's manual skills to stop the penetration when completing a hole and already known that human bone is consist of cancellous and cortical bone that are very differ in density and thickness. This soft and hard bone tissue could be estimated in order to assist the surgeon while drilling a bone. Many researcher and organizations are trying to build any devices or ways in order to improve the bone drilling technique which is relatively low cost and time saving.

Besides drilling, pedicle screw fixation process is also important in dealing with musculoskeletal system especially in vertebrae region such as cervical, lumbar and thoracic vertebrae. Laine et al, (2000) has proposed that transpedicular screw insertion is a demanding technique due to considerable variability in the human anatomy and to the fact that it is impossible to guide a screw exactly in three planes of space based on the two-dimensional image information of fluoroscopy. The pedicle screw fixation is almost same or related to drilling process because it need to produce a hole for fixed screw and it is totally depend on the surgeon manual skill to complete a hole. The surgeon has to put enough pressure according to the bone tissue either hard or soft. Sometimes, it is hard for surgeon to complete a hole in cervical or thoracic region because the anatomy of the region itself are closed to spinal cord and major vein that could lead to other side effect to the patient if the process goes wrong. Pedicle screw misplacement rates of between 21.1 and 39.8% have been reported in clinical studies with conventional insertion techniques and an adequate postoperative CT assessment has been studied (Castro et al, 1996; Gertzbein et al, 1990; Jerosch et al, 1992 and Laine et al, 1997). So, realizing this shortage that could risk the patient, this study would enhance the process with the knowledge of acoustic emissions (AE) to unsure the safety of the patients and give courage and confident to the surgeon while doing this procedure.

In this project, the acoustic emissions (AE) technique was used to monitor the pedicle screw fixation process. The technique is one of non-destructive test (NDT) group and it application is still new in term of monitoring the drilling process. This technique was developed base on the theory of transient elastic waves that emit from rapid strain energy release inside a material that is subjected to stress. Acoustic emissions are a suitable method for recognizing the crossing of interfaces between hard and soft tissues and to discriminate among layers of different tissues. Acoustic emissions signal events will give different results when across these layers and these results will be investigated in order to study the trend and it characteristics.

During pedicle screw fixation procedure, elastic wave is produced by pedicle probe used by surgeon when perforating a hole. The AE sensor will be attached at the pedicle probe and will sense the transient elastic wave known as AE signal events. The AE signal events will further analyzed to indicate the component’s condition.

Practically, the AE signal events will further analyzed into the time and frequency domain. Time and frequency domain will justify some parameter such as peak amplitude, signal duration, detection threshold, time, period, velocity, acceleration and frequency.

1.2 OBJECTIVES

For this project two main objectives are listed:

- To investigate the Acoustic emissions (AE) signal events in cervical bone during pedicle screw fixation procedure when through two type of bone tissue; hard and soft bone’s tissue.
- To study the trend of the Acoustic emissions (AE) signal events for penetration level during the hole perforation in pedicle screw fixation procedure.

1.3 SCOPE OF THE STUDY

The definition of scope is important to make sure the research is done towards the right direction. For this research, the study will use the acoustic emissions technique to monitor the pedicle screw fixation procedure. A same device was used to perforate a bone that consists of hard and soft bone’s tissue.

1.4 IMPORTANT OF STUDY

This research is important in order to monitor the pedicle screw fixation procedure that vital in orthopedic surgery. It can assist the surgeon in the perforation process to be more precisely and accurately. This research also can help the surgeon from doing carelessly mistake in order to save life. The interests in monitoring bone drilling or perforation process using non destructive testing (NDT) become very essential since it is relatively low cost and the result could be save more life and pain.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about basic bone anatomy, pedicle screw fixation process, pedicle screw fixation's tools, acoustic emissions (AE) signals and a few related studies and journals that have been done by current researchers. Besides, the information about the software that has been used also included here. All this information is important before furthering to the analysis and study later.

2.2 BASIC BONE ANATOMY

A bone is made up of several different tissues working together: bone or osseous tissue, cartilage, dense connective tissue, epithelium, adipose tissue and nervous tissue (Tortora et al, 2006). For this reason each individual bone in human body is considered an organ. There are several functions of bone tissue. Firstly, it is supports soft tissue and provides attachment for skeletal muscles. Secondly, it is use to protects internal organs and assists in movement along with skeletal muscles. Thirdly, it is use to stores and releases mineral. Bone tissues also contain red bone marrow which produces blood cell and yellow bone marrow which stores triglycerides (fats) (Tortora et al, 2006).

Bone in human and other mammal bodies is generally classified into two types of tissues that is cortical bone also known as compact bone and trabecular bone also known as cancellous or spongy bone. These two types are classified as on the basis of porosity and the unit microstructure. Cortical bone is much denser with porosity ranging between 5% and 10% (Tortora et al, 2006). Cortical bone is found primary in the shaft of long bones and form the outer shell around spongy bone at the end of joints and vertebrae. Spongy bone is much more porous with porosity ranging from 50% to 90% (Tortora et al, 2006). It is found in the end of long bones in vertebrae and in flat bones like the pelvis.

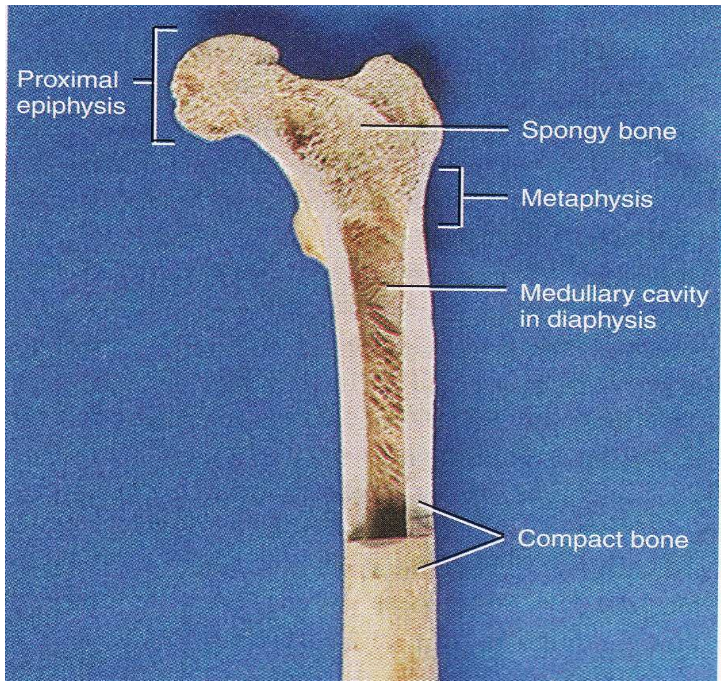


Figure 2.1 (a): Partially sectioned femur.

Source: Tortora et al (2006)

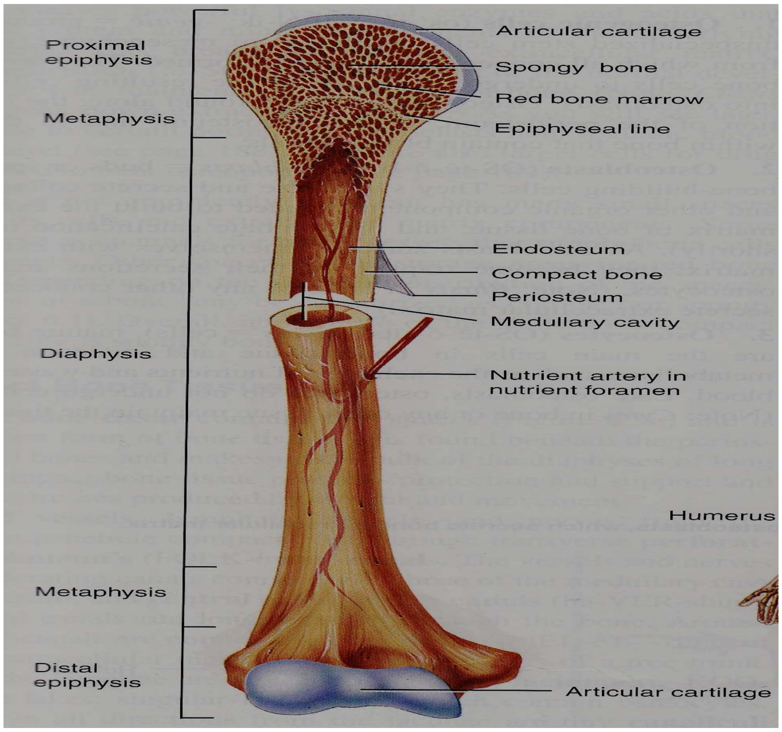


Figure 2.1 (b): Partially sectioned humerus.

Source: Tortora et al (2006)

2.2.1 Compact Bone Tissue

In compact bone tissue contains few spaces and is the strongest form of bone tissue. Usually, compact bone tissue is found beneath the periosteum of all bones and it form as diaphyses of long bones. Furthermore, the used of compact bone tissue is to provides protection and support and resists the stresses produced by weight and movement. Osteons or haversian systems are the components of compact bone tissue that arranged into repeating units. These osteons are aligned in the same direction along lines of stress. As a result, the shaft of long bone resists bending or fracturing even when considerable force is applied from either end (Tortora et al, 2006).

2.2.2 Spongy Bone Tissue

Different from compact bone tissue, spongy bone tissue does not contain osteons. Spongy bone contains of lamellae arranged in an irregular lattice of thin columns called trabeculae. The macroscopic spaces between the trabeculae help make bone lighter and sometimes it can be filled by red bone marrow. Spongy bone tissue forms most of the bone tissue of short, flat and irregularly shaped bones (Tortora et al, 2006). The trabeculae of spongy bone tissue also are precisely oriented along lines of stress which it is very important to help bones resist stresses and transfer force without breaking. Usually, spongy bone tends to be located where bones are not heavily stressed or where stresses are applied from many directions. Spongy bone tissue is light, which reduces the overall weight of a bone and as a result it move more readily when pulled by a skeletal muscle. The tarbeculae of spongy bone also support ad protect the red bone marrow (Tortora et al, 2006) .

2.3 VERTEBRAL COLUMN

The vertebral column also called spine or backbone formed about two-fifths of human total height and consists of a series of bones called vertebrae. The vertebral column consists of bone and connective tissue; the spinal cord that is surrounds and protects consists of nervous and connective tissues (Tortora et al, 2006). Besides, the vertebral column functions as a strong, flexible rod with elements that can move forward, backward and sideways either rotate. In addition to protecting and enclosing the spinal cord, it supports the head and serves as a point of attachment for the ribs, pelvic girdle and muscles of the back. The vertebral column can be show as in figure 2.2.

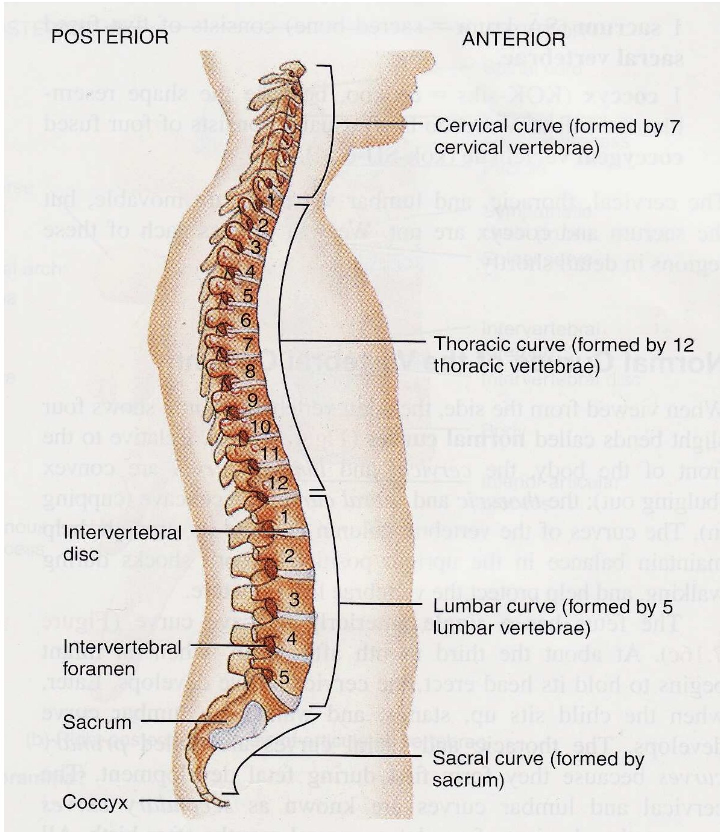


Figure 2.2: Right lateral view showing four normal curves.

Source: Tortora et al (2006)

2.3.1 Region of vertebral column

The vertebral column consist of five regions that vertebrae in each region are numbered in sequence, from superior to inferior. These regions are cervical region, thoracic region, lumbar region, sacrum and lastly is coccyx. But for this study only two major region will be explain in general and with basic anatomy. According to the physician the most risky part during the process is the cervical region because it is smaller compared to other region and also close to blood line and spinal cord itself.

2.3.2 Cervical Region

The cervical vertebrae (C1-C7) as shown in figure 2.3 (a) are considered smaller if compare with other vertebrae except those that form the coccyx. However, the cervical vertebral arches are larger. As shows in the figure 2.3 (b), all cervical vertebrae have three foramina: one vertebral foremen and two transverse foramina.

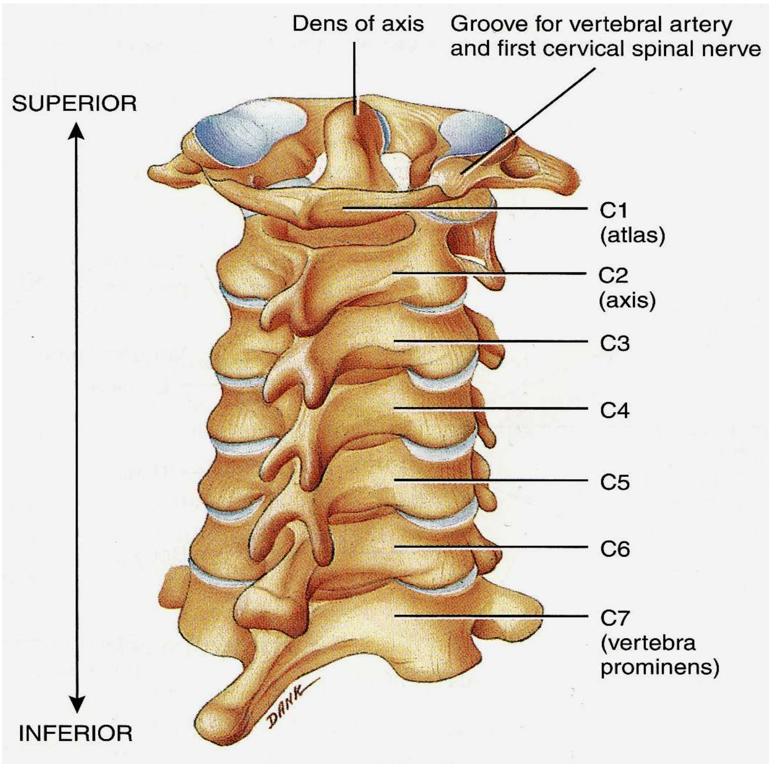


Figure 2.3 (a): Posterior view of articulated cervical vertebrae.

Source: Tortora et al (2006)

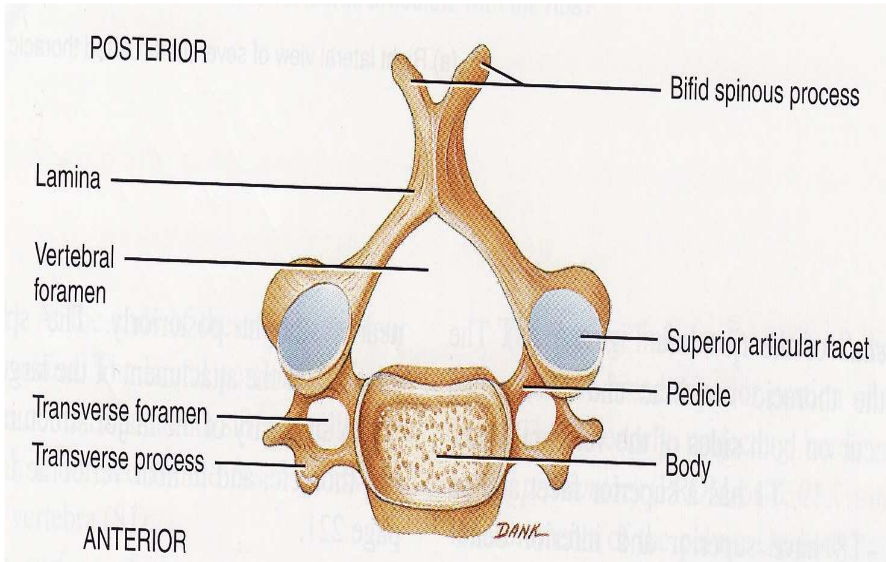


Figure 2.3 (b): Superior view of a typical cervical vertebra.

Source: Tortora et al (2006)

2.3.3 Thoracic Region

The thoracic vertebrae (T1-T12) as shown in figure 2.4 are considerably larger and stronger than cervical vertebrae. The spinous processes on T1 and T2 are long, laterally flattened, and directed inferiorly. But, in contrast the spinous processes on T11 and T12 are shorter, broader and directed more posteriorly.

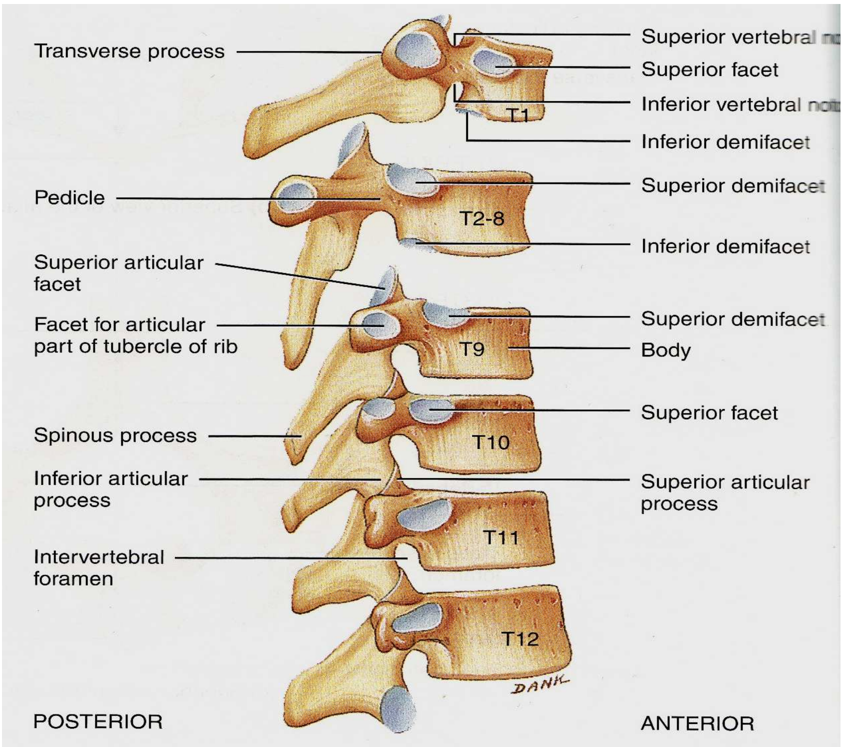


Figure 2.4: Right lateral view of several articulated thoracic vertebrae.

Source: Tortora et al (2006)

2.3.4 Lumbar Region

The lumbar vertebrae are the largest and strongest in the vertebral column (Tortora et al, 2006). It is because the amount of body weight supported by the vertebrae increases toward the inferior end of the backbone. Lumbar region projections are short and thick. The superior articular processes are directed medially instead of superiorly, and the inferior articular processes are directed laterally instead of inferiorly. The spinous processes are quadrilateral in shape, thick and broad, and project nearly straight posteriorly like in figure 2.5. The spinous processes are well adapted for the attachment of the large back muscles.

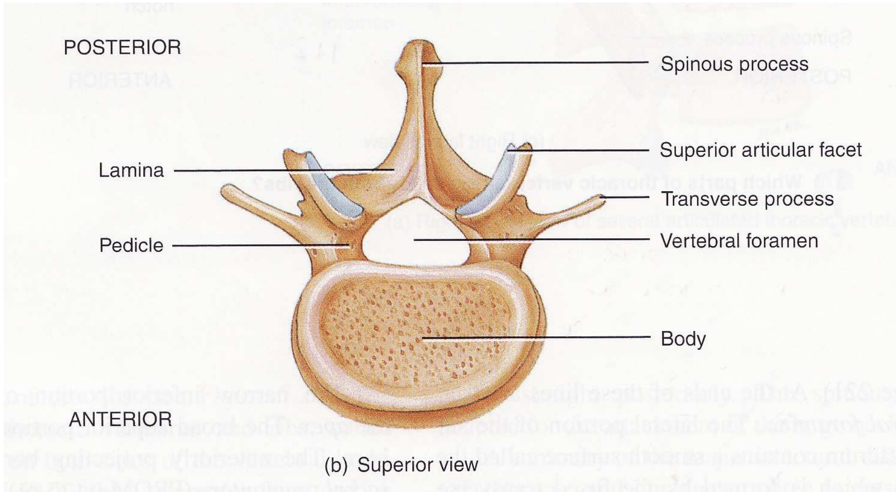


Figure 2.5: Superior view of lumbar vertebra.

Source: Tortora et al (2006)

2.4 PEDICLE SCREW FIXATION

The procedure called a pedicle screw fixation is a surgical procedure that secures two bones to one another to in effect make one bone. Usually this procedure involved lumbar region as shown in figure 2.6 (a) or other vertebrae due to the following acute and chronic instabilities or deformities of the thoracic, lumbar and sacral spine: degenerative spondylolisthesis with objective evidence of neurological impairment, fracture, dislocation, scoliosis, kyphosis, spinal tumor, and failed previous fusion (pseudarthrosis). The pedicle screw system also intended to provide immobilization and stabilization of spinal segment in skeletal vertebrae.

The first part of the procedure is finding if any nerves are being pinched by using an operating microscope. The bone from the back of the spine would be remove during this part of the procedure to give the access to the nerves as they could be decompressed and also to use the bone later in fusion.

The second part of the procedure is called the instrumentation. For example, four screws are placed, two in the bone above and another two in the bone below. These screws are secured with steel rods approximately the diameters of a pencil. Finally, by using X-rays, the position of the screws is carefully checked at the time they are placed to make sure the two bones that are slipping on one another are secured to each another. Figure 2.6 (b) shows the exact position of the pedicle screw in the vertebral body.

Then, the third part of the procedure is called fusion. As already know, the rods and screws are extremely strong but they still have the potential to loosen over time and to make sure that the bone secured to one another, bone is placed that will grow from one to the other creating a strong bridge that will last forever. The bone that is placed is a combination of the bone that had been taken earlier in the procedure and it is mixed with a special material to stimulate the bridging of bone from one vertebral segment to the other.

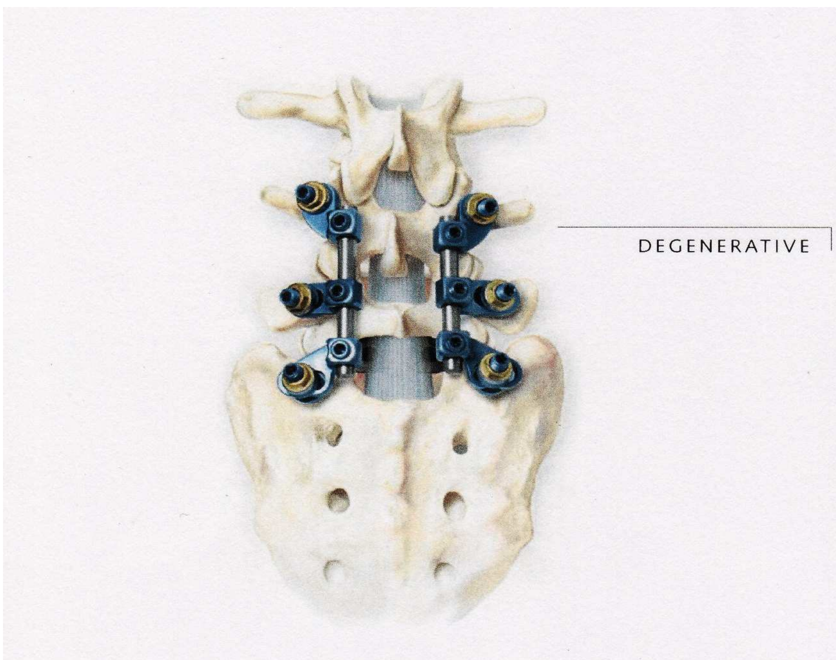


Figure 2.6 (a): Pedicle Screw fixation at lumbar spine

Figure 2.6 (b): Screw insertion diagram

2.4.1 Pedicle Screw Fixation's Tools

To proceed with the pedicle screws fixation procedure need to have instruments that would assist in the procedure. The instruments involved in this procedure are pedicle probe, pedicle screw and rod. All these instrument are made from titanium because of it is behaviors that strong and lightweight, high corrosion resistant, biocompatible and non-ferromagnetic material. To insert pedicle screws, a long, thin, metal probe is inserted through the pedicle and into the vertebral body, forming a hole for reception of the screw. There are variety of pedicle probe such as gear shift pedicle probe and the Fox pedicle probe. The gear shift probe has a round head on its proximal end, whereas the Fox probe has a flat disc-shaped head on its proximal end as in figure 2.7 (a). Meanwhile, for pedicle screws are available in variety of diameters depend on the company ranging from 4.75mm through 8.50mm. To increase the versatility of the pedicle screw as shown in figure 2.7 (b), polyaxial washers is used to facilitate three dimensional adjustments, thus minimizing pre-loading of patient anatomy and implant construct.

Figure 2.7 (a): Example of Fox probe

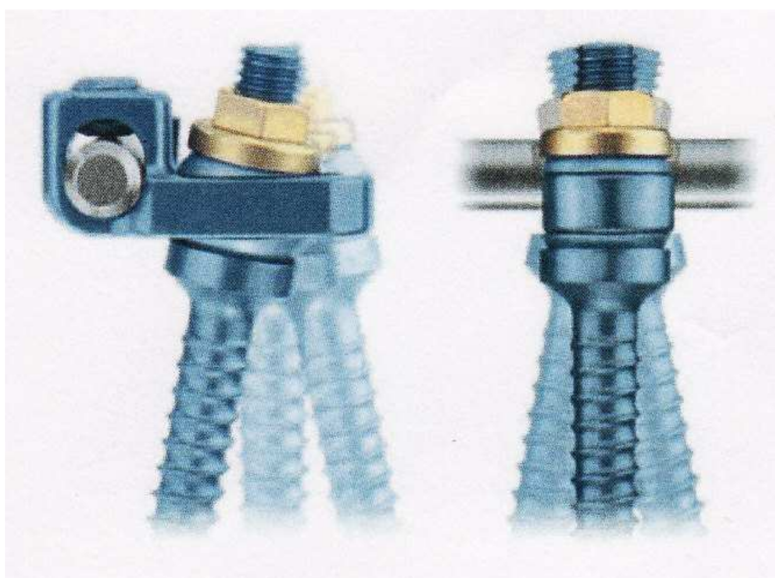


Figure 2.7 (b): Pedicle screw

2.5 ACOUSTIC EMISSIONS (AE) METHOD

Acoustic emissions monitoring is one of non-destructive testing (NDT) methods and become most available and useful methods in monitoring process or behavior. Acoustic emissions are pressure waves generated due to transient release of energy when a material is subjected to mechanical, thermal or chemical changes causing irreversible deformations or changes in atomic arrangement (Rao A.K, 1990). It can give an intermediate indication of the response and behavior of a material under stress, intimately connected with strength, damage and failure (Zohari, 2008). Acoustic emissions (AE) is an inspection technique by means of detecting elastic waves due to dynamic motions at an AE source, such as cracking, delamination, cleavage, fretting and others. Acoustic emission method also used for the investigation of dynamic behavior of materials especially in study of deformation, fracture and corrosion. It also used in monitoring corrosion process, phase transformation and liquid solid transformation usually in monitoring chemical reaction. Besides that, acoustic emissions or high-frequency microseismic events also available for crack initiation and propagation in solid material such as rocks and buildings. Another used of acoustic emissions is it has certain advantage to detect the onset of fatigue damage with its high sensitivity, real-time monitoring and remote-sensing capability.

Up to the present, many research and publications have been made since of the 20th century especially in the area of seismology, mining, physics and metallurgy. These publications also involved for monitoring dynamic process. During the 1950s and 1960s researchers delved into the fundamentals of acoustic emission, developed instrumentation specifically for acoustic emissions, and characterized the acoustic emissions behavior of many materials. Acoustic emissions were starting to be recognized for its unique capabilities as a non-destructive testing method for monitoring dynamic processes.

The term of acoustic emissions is used to describe the phenomenon of generation and propagation of elastic waves as a result of sudden release of energy stored at a certain point of the studied medium. Energy emitted in this process is changed into heat, mechanical work and a small part is emitted as elastic waves. These elastic waves are called an acoustic emissions signal. On the other hand, the source of the acoustic emissions signal is defined as a location or structural element that emits the acoustic emissions signal. Acoustic emissions also can be described as a shock wave inside a material, which is under stress Tandon, N. et al (2005).

2.6 TYPE OF ACOUSTIC EMISSION

Usually there are only two types of acoustic signal; continuous signal and burst signal. These signals are as shown in figure 2.8. For this research, both type of signal were detected. Generally, most of it was burst signal because by burst signal it is easy to determine the characteristic of the acoustic emissions.

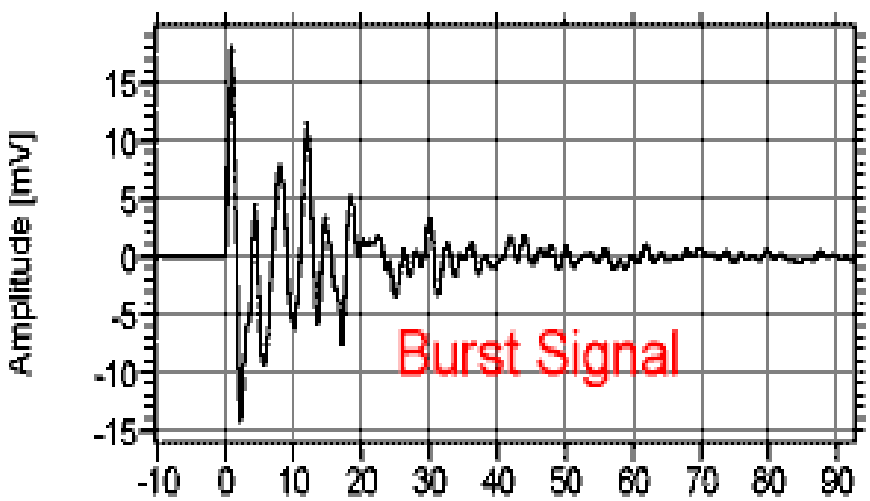


Figure 2.8 (a): Burst signal

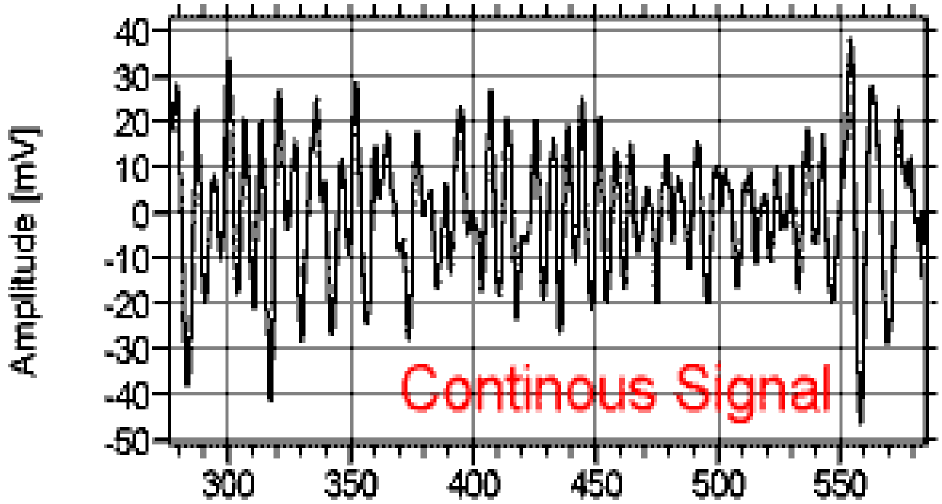


Figure 2.8 (b): Continuous signal

Source: www.ndt-ed.org

2.7 PARAMETER OF ACOUSTIC SIGNALS

In many analysis process, the time domain AE parameters that been measured for the analysis are AE burst, threshold, ring down count, cumulative counts, event duration, amplitude, energy, RMS amplitude, kurtosis, counts, rise time, peak amplitude, signal duration and RMS voltage etc. The most commonly measured AE parameters are peak amplitude, counts and events of the signal Tandon, N. et al, (2005).

Different research will use different AE parameters in analysis. The differences could be seen through all the publication as in the references. There are some AE parameters that were analyzed to find the relation between these parameters and the analyzed variables. It is important to know that every parameter will give different expression and meaning. For example, in this study RMS amplitude is vital and it is represent the energy of the AE signal. Meanwhile, frequency will give how fast the AE activity and hits will show how much the AE activity.

2.8 ACOUSTIC EMISSION SIGNAL PROCESSING

Acoustic emissions signal is known as non-stationary and usually comprises overlapping transients whose waveform and arrival times is unknown. The signal processing is vital for this study to get the accurate results. In data analysis, the signal processing is consisting of three basic steps; data acquisition, data processing and results interpretation. The main objective for signal processing is to gain the indirect information from the signal.

2.8.1 Time Domain Analysis

In this study, indices such as the peak level, root mean square (RMS) level and the frequency are used in the analysis to obtain the project's objective. There is not a statistical quantity since the peak level occurs only once and is not a reliable index to detect damage in continuously operating systems. The crest factors as equation 2.1 also vital for this study and it is defined as the ratio of the peak to RMS level. It includes information from both of the peak and RMS level for continuous signal y(t). For RMS amplitude can be defined as equation 2.2. If the fail occur progressively, the RMS signal level will be increasing gradually although the crest factor might be showing a decreasing trend.

$$\text{Crest factor} = \frac{y_{peak}}{y_{rms}} \tag{2.1}$$

$$y_{rms} = \sqrt{\frac{1}{t_1 - t_2}\int_{t_1}^{t_2} y^2 \, dt} \tag{2.2}$$

Meanwhile for the same continuous signal y(t), the energy can be given as,

$$\text{Ey} = \int_{-\infty}^{\infty} |y(t)|^2 \, dt \qquad (2.3)$$

2.8.2 Frequency Domain Analysis

The frequency domain analysis is a plot of the amplitude of vibration response versus the frequency and could be derive by using the fast Fourier analysis of the time waveform. This analysis will show much valuable information about the subject condition. The changes can be detected more easily compared to changes in overall vibration levels, this characteristic be more valuable for this study.

2.9 ADVANTAGES OF ACOUSTIC EMISSION TECHNIQUE

Acoustic emissions could give many advantages compared to conventional inspection method. Acoustic emissions as a passive method other than active non-destructive testing method (NDT) has drawn great attention because of its applicability to on-stream surveillance of structures or any dynamic processes. One important point is the capability of acoustic emissions to acquire data very simply but with high sensitivity, so that the development of non-contact sensing technique is particularly very important. This method also is relatively low cost and can give early and rapid detection of defects, leaks, flaws, cracks etc.

Besides, the acoustic emissions inspection was designed to inspect 100 percent of a structure from only a few locations. It gives an immediate indication of the response and behavior of a material under stress intimately connected with strength, damage and failure. A major advantages is acoustic emissions could minimizes the plant downtown for inspection because it does not require access to the entire examination area to find defected area. Furthermore, acoustic emissions also have minor disturbance of insulation.

In the next generation, acoustic emissions is to expect to be a technique not only in monitoring conditions but also in repairing damaged structures combined with an active-adaptive technique using a device called "solid state actuator" or known as "Smart Materials and Structure". Acoustic emissions are considered to be a very promising technique together with such sensing techniques as optical fiber, shape memory alloy and electro-rheological fluid. Thus, acoustic emissions can play a very important roll to monitor, evaluate and repair structures.

2.10 REVIEW STUDY OF CURRENT ACOUSTIC EMISSION METHODS

A collaborative virtual environment for the simulation of temporal bone surgery by Dan Morris et al, said that sound is a key source of intraoperative feedback, as it provides information about drill contact and about the nature of the underlying bone. The study simulates the sound of the virtual burr as a series of noisy harmonics, whose frequency modulates with applied drilling force. In Dan Morris et al, sound can also be a key indicator of bone thickness intraoperatively sound quality and frequency change significantly as the drill contacts a thin layer of bone, providing a warning that the surgeon is approaching sensitive tissue. In their simulator, the pitch of the synthesized sound increases when the drilled area becomes thin. In order to estimate the thickness of bone regions, they used a raytracing algorithm similar to that used for haptic rendering. At each voxel that is determined to be on the surface of the bone, the surface gradient is used to approximate the surface normal, and a ray is cast into the bone along this normal. The ray is traced until it emerges from the bone volume, and the thickness is estimated as the distance from the ray’s entry point to its exit point. For sound synthesis, this thickness is averaged over all surface voxels with which the drill is in contact. The computed thickness values are also used to visually shade thin bone, which tends to appear red and translucent as the drill approaches soft tissue.

Meanwhile, in pedicle screw fixation for cervical transpedicular screw fixation knowing the exact diameter of the pedicle size is important especially for Malaysians population because there are vitals structures adjacent to the pedicles. The standard pedicle screw may not be accommodating for Asian population and that why it is important to firstly measure the pedicle diameter before any transpedicular screw fixation is done. According to Yusof et al (2006), the study of pedicles in a local population is imperative before any attempt for cervical fixation using a pedicle screw is initiated.

As mentioned earlier, acoustic emissions also have been utilized for monitoring process and many studies have been done to prove that. M T Mathew et al (2008) did a laboratory testing to detect AE signals from insert-milling operation and to correlate the various signal parameters with the status of the tool. In the study, they use AC 750 2425 piezoelectric transducer to detect the acoustic emission signal. The signal then was amplified using a preamplifier (60 dB gain) and filtered using a wide band filters (30 KHz–2 MHz) and was recorded using AET 5500 AE Signal Analyzer. The experiments were carried out using single or two inserts (adjacent and opposite) and three inserts in the cutter for different cutting conditions. And one of the conclusions from the study is milling being an intermittent cutting process offers lot of difficulties for tool condition monitoring thus there is a need for more sophisticated and advanced signal processing instrumentation systems and also signal processing algorithms, which can help in using AE effectively as a sensor.

While current study are more interested in finding the relation between AE parameters and status of tool in milling process, Krzysztof Jemielniak et al (1997) were interested in study of cutting forces and acoustic emission measures as a function of tool wear for different cutting parameters and its capability in the tool condition monitoring process. They developed special software simulating feed forward, back propagation (FFBP) neural networks to employ for integration of the selected measures into one tool wear indicator. The analyzed network had eight continuous inputs and one continuous output.

AE techniques also being used for monitoring fatigue failure process in structure or material like wind turbine blade. The wind turbine blade is always subjected to repetition stress because of rotation that contributes to the fatigue failure to occur. Many studies have been done to improve the monitoring process like A G Beattie study of AE monitoring of wind turbine blade during a fatigue test. Wei and McCarty also performed fatigue tests on a 7. 5 and a 13 meter wind turbine blade and monitored the AE during static tests between intervals of at least 10,000 cycles.

In A G Beattie study, he found that fatigue tests of large fiberglass reinforced plastic (FRP) wind turbine blades can be monitored by acoustic emissions techniques and that the monitoring can produce useful information. The system showed that the peak load was too high so that it could have been decreased before significant damage was done to the blade.

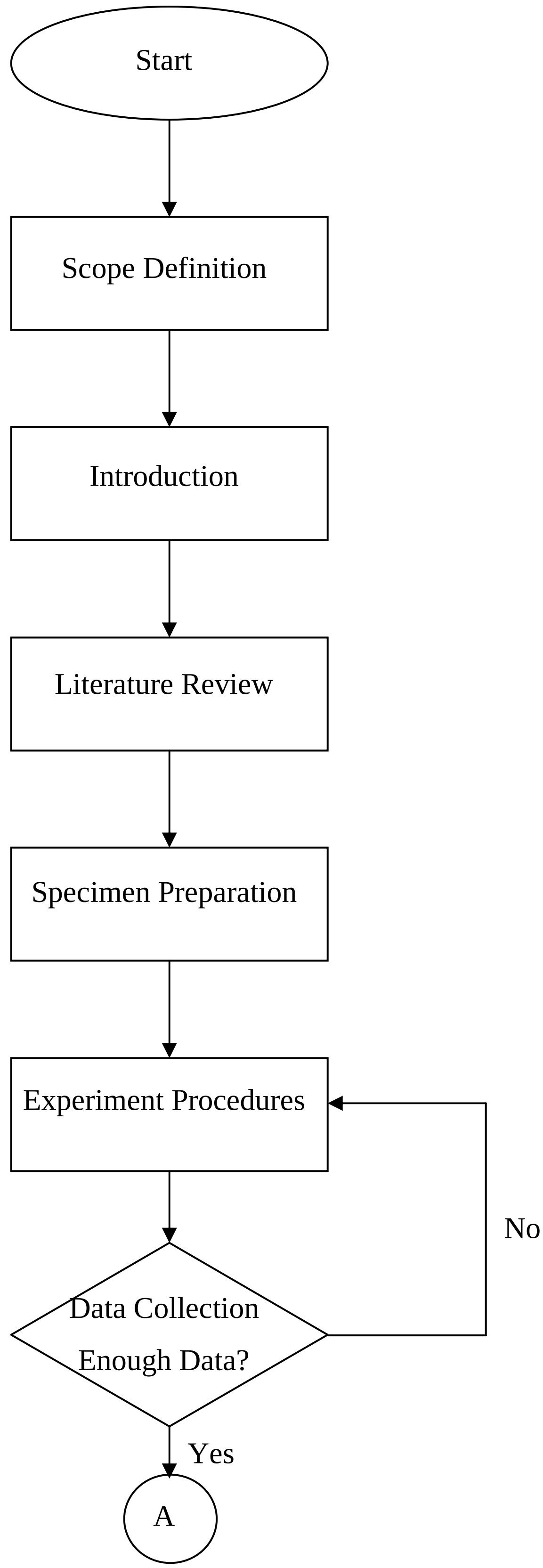
CHAPTER 3

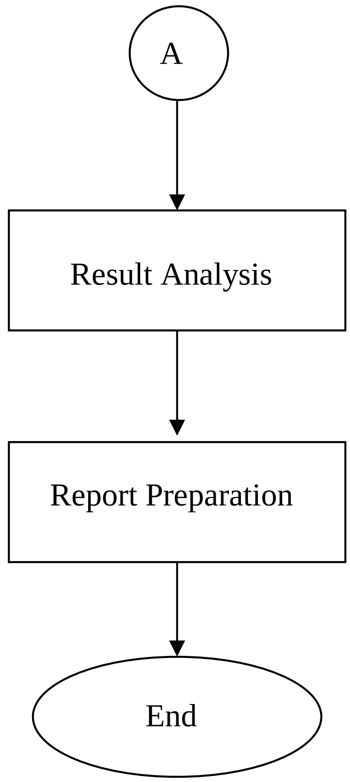
METHODOLOGY

3.1 INTRODUCTION

Project methodology play important role in order to design and analyze the testing procedure in the process of pedicle screw fixation. This project methodology would become a guideline for the overall project progress from beginning until finish. Before starting to design this testing procedure on the spinal vertebrae function and characteristic of the spinal and bone itself should be known. So, at the beginning of the project, some research and literature review about the bone and some related study are very important to enhance knowledge.

3.2 FLOW CHART




A
Result Analysis
Report Preparation
End

3.3 SPECIMEN AND TOOLS PREPARATION

The experiments involved the usage of measurement tools which were broadband acoustic sensor and pre-amplifier. The test was done to get the acoustic emission signal events from spinal bone especially at cervical vertebrae during a pedicle screw fixation procedure. In order to precede with the experiment a bovine vertebra was used to replace the real human vertebrae. Although a bovine vertebra was used the results for this experiment still can be use because the anatomy and characteristic of the bovine vertebrae were same as exactly to the human vertebrae. Another reason why a bovine vertebra was used is because it is easy to get from any butcher store in Malaysia with a lower cost. For the tools used in the pedicle screw fixation procedure were pedicle probe, pedicle screw and others as explain in the previous chapter.

3.3.1 SPECIMEN PICTURES

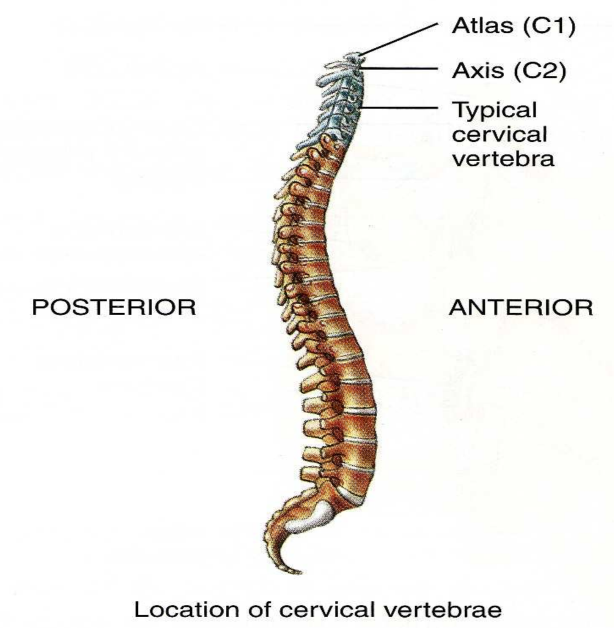


Figure 3.1(a): Location of cervical vertebrae

Source: Tortora et al (2006)

Figure 3.1(a) shows the location of the typical cervical vertebra on the human vertebrae. This cervical region will be the main location for the pedicle screw fixation procedure. For this study also, a bovine vertebrae as figure 3.1(b) will be use instead of the human vertebrae to fulfill the project's objective.

Figure 3.1(b): Bovine vertebrae

3.3.2 DETAIL SPECIFICATION

In order to use the measurement tools, the details specification about every each tool need to be described to get the accurate results. In this experiment, the tools used were sensor, preamplifiers, filters, DiSP card and computer with appropriate software for analyzing the acoustic emission signal events as shown in hardware architecture in figure 3.2. The heart of the acoustic is the sensor. The function of the sensor is to convert the acoustic wave energy emitted by the source into usable electric signal typically voltage time signal. Another tool is pre-amplifier. Pre-amplifier is the first stage of the instrumentation system and its main function is to enhance the signal level against noise. Since the sensor produces charge proportional to the source intensity, the pre-amplifier must be located near the sensor. Hence normally a preamplifier is used along with the transducer and the two together forms the front-end of the acoustic emissions instrumentation. Meanwhile, filter plays an important role in allowing the amplified signal from sensor and attenuating unwanted noise. An ideal filter of passive or active network allows the desired frequencies with unit gain and rejects unwanted frequencies. Filters are also designed for different bandwidth and can be plugged to preamplifier to meet the specific requirements. So, the correct specifications for these tools are really important in the experiment to unsure the accuracy of the acoustic signal.

3.3.2.1 Hardware Architecture

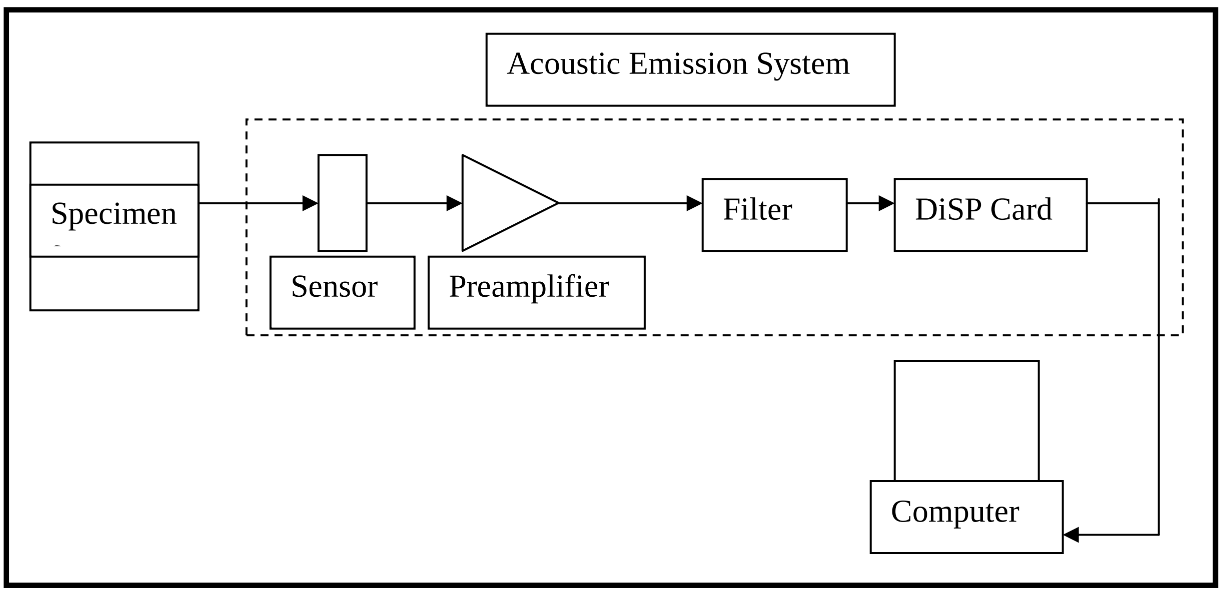


Figure 3.2: Acoustic Emission System

3.3.2.2 Acoustic Emissions Tools

Figure 3.3: AED-2000V

In this experiment, the instrumentation for the acoustic emission system is single channel virtual acoustic emissions instrument model: AED-2000V as shown in figure 3.3. It is designed to work with Windows-based PC to provide complete setup and data acquisition control, real time graphics, and data storage. This model also includes new features such as parametric inputs, alarm outputs and an external hold. It also brought with AC adapter (110V/220V), 9-pin serial cable including Integral preamp AE sensor with 400 kHz resonance in figure 3.4, 40 dB gain and BNC coax connector as shown in figure 3.5. Besides, it also has magnetic attachment for Model i400 integral preamp sensors and Coaxial RG-58 cable as in figure 3.6 with 25 feet long and BNC coax connectors. Meanwhile, by using this model also need to have Acoustic Emission Detector Software (AED Software) version 2.1.3 as shown in figure 3.7. It provided data logging and uploading to PC, with real time graphics and Windows based.

Figure 3.4: Integral preamp AE sensor

Figure 3.5: BNC Coax Connectors

Figure 3.6: Coaxial RG-58 cable

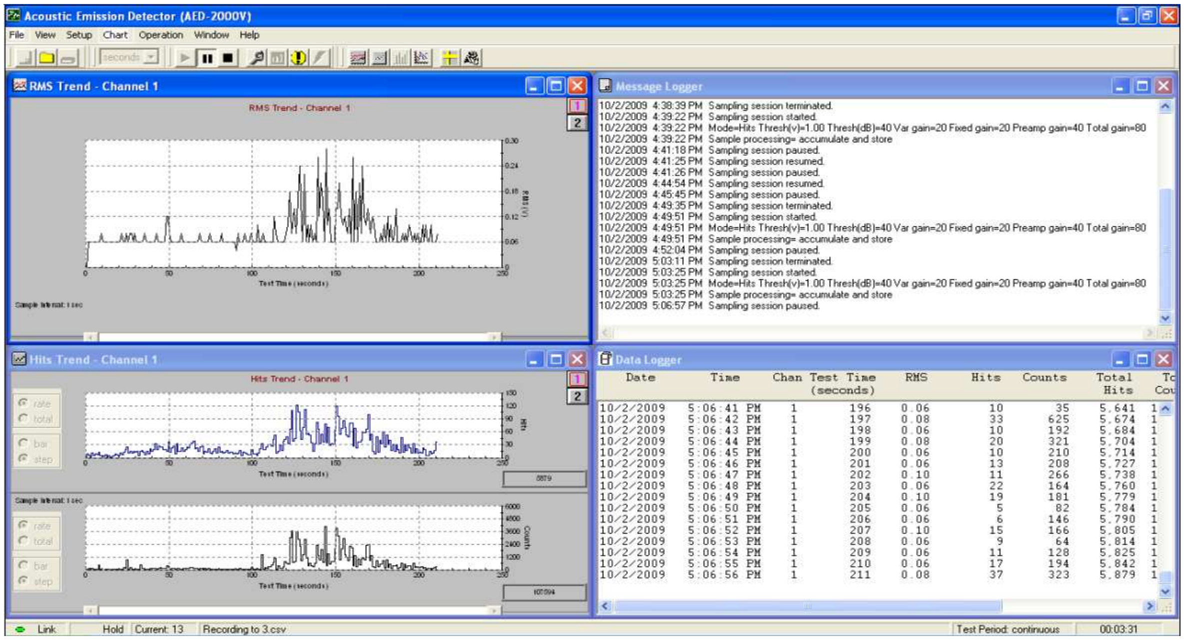


Figure 3.7: Acoustic Emission Detector Software

3.5 TEST'S PROCEDURE

For this study, two experiments were conducted by using two bovine vertebrae in order to achieve the objectives. The test or the experiment done was to show that the acoustic emissions signal events could be detected during the pedicle screw fixation procedure. In experiment in first bone, the purpose is to evaluate the pattern of acoustic emissions signal events graph when the screw driver that acts like pedicle probe is perforated through the bone. While in experiment for second bone, an indicator of 1.5cm long as in figure 3.8, is set up at the screw driver in order to find the exactly time where the crack propagation occur. The indicator is set up by making the thick and width of bone as in figure 3.9.

Before the procedures begin, a sensor will be attached to a screw driver that will be used as a pedicle probe as in figure 3.10. By using that "pedicle probe" a hole was created by giving enough pressure to the bone after the starting point and right angle is recognized as in figure 3.11. This pedicle probe is used by hand to actually understand, observed and feels the resistant given by the vertebrae bone tissues. This resistant is very important to surgeon because it can make sure the trajectory of the screw hole was accurate enough to avoid any wall penetration. It could lead to greater risk to the patients if the trajectory of the screw is unacceptable. The sensor will be on during the procedure was done to monitor and let the acoustic emissions signal events being captured.

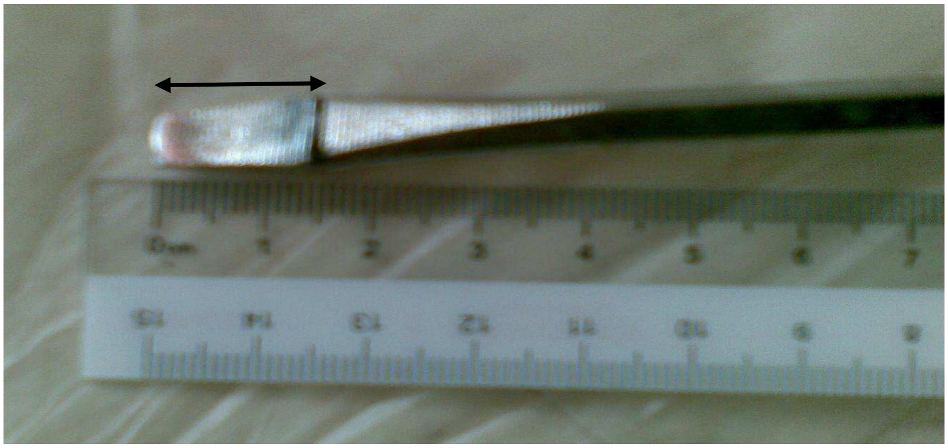


Figure 3.8: Indicator

Figure 3.9: Indicator’s reference

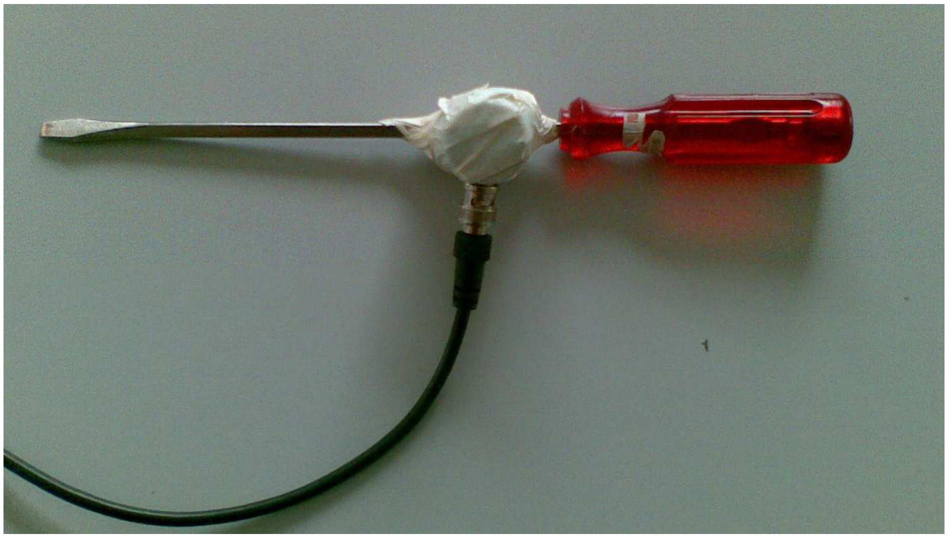


Figure 3.10: Screw driver

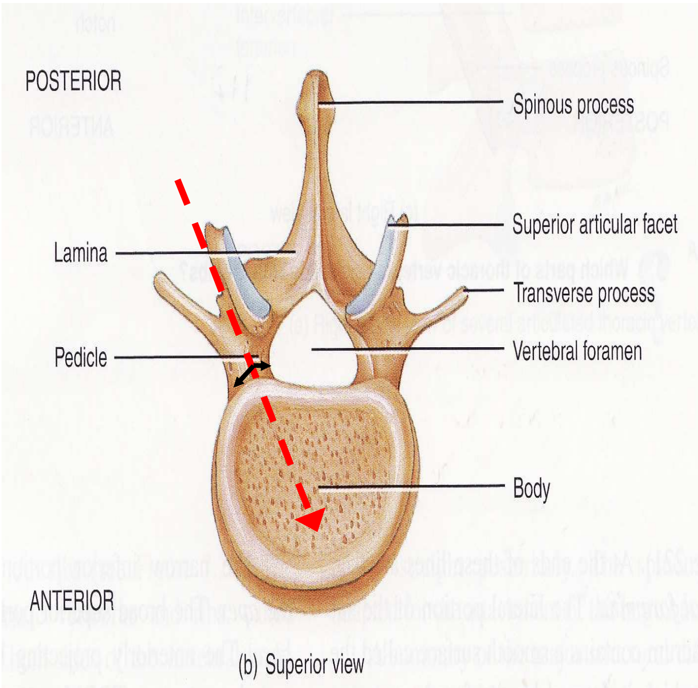


Figure 3.11: Location of screw insertion

3.6 EXAMPLE OF HOLE'S PERFORATION

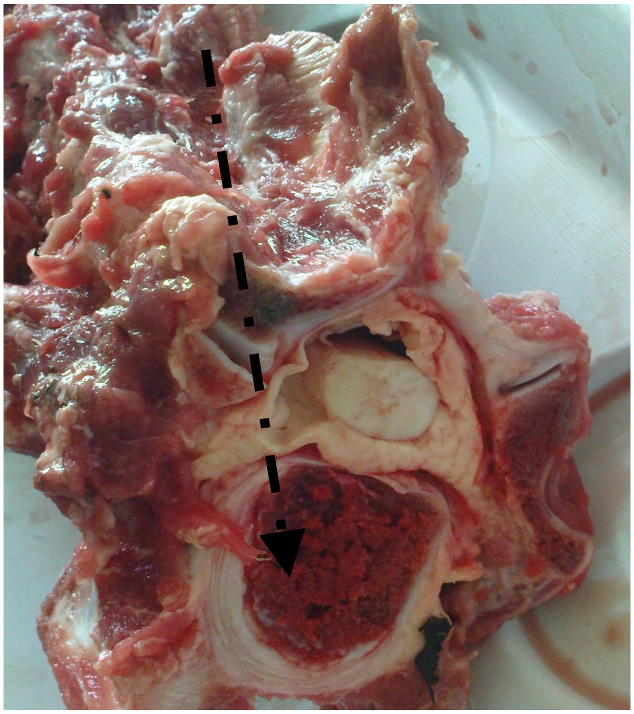


Figure 3.12

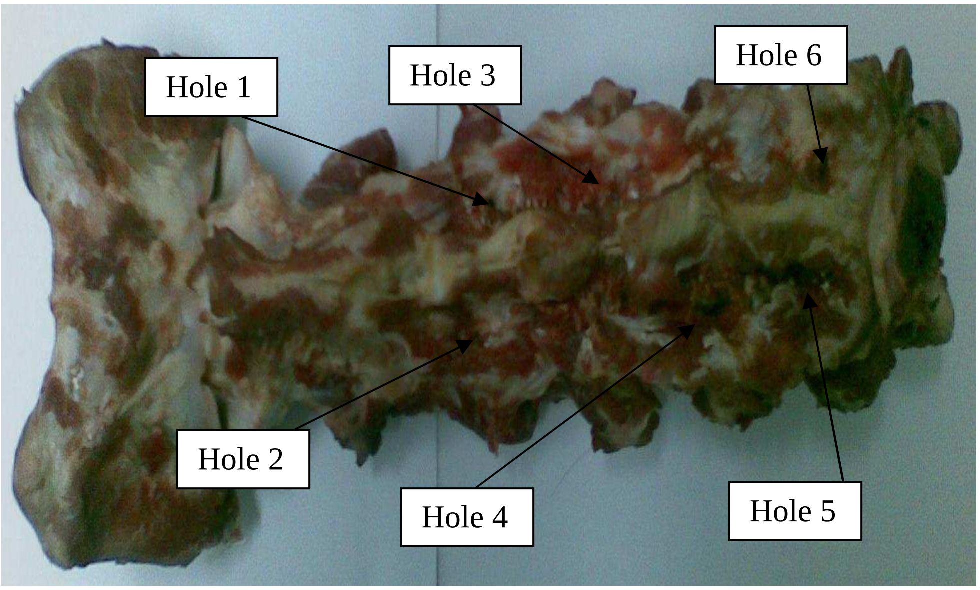


Figure 3.13: Hole's perforation for experiment on the first bone

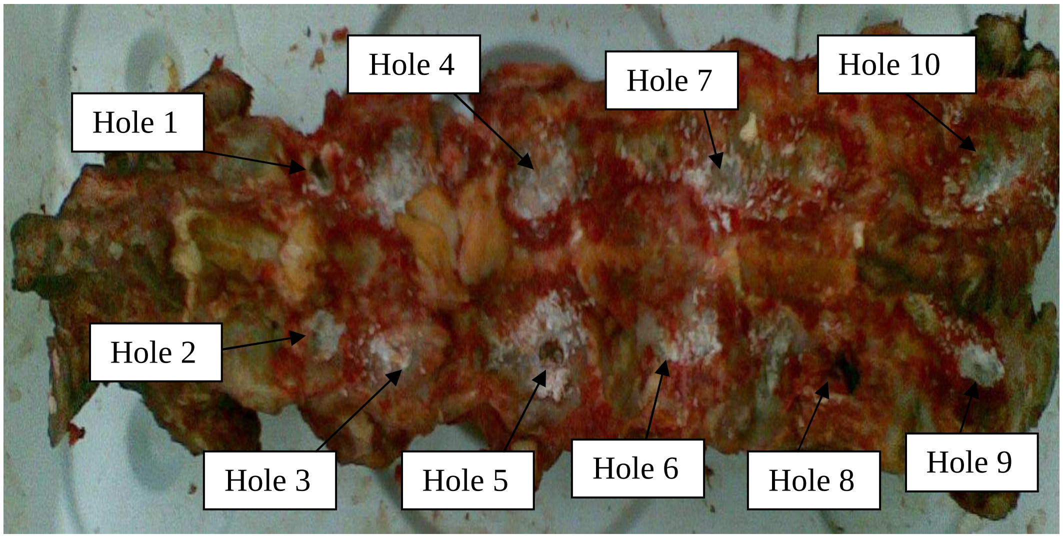


Figure 3.14: Hole’s perforation for experiment on the second bone

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

As mentioned in previous chapter, two different procedures were conducted to achieve the objective for this project. All the procedure was critical since it is the main steps to prove the objective. The first procedure for the experiment on first bone is to investigate the pattern of the Acoustic Emission signal events graph when the "pedicle probe" is perforated through the bone and in the second procedure for the experiment on second bone, an indicator is set up at the "pedicle probe" in order to find the exactly time where the crack propagation occur. The example of acoustic emission signal events that viewed using software Acoustic Emission Detector Software version 2.1.3 was as in the Appendix 2.

4.2 EXPERIMENTS ON THE FIRST BONE

Figure 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 show the results for hits and cumulative hits from the first experiment on the first bone for each hole. This result collected by the Acoustic Emission Detector Software during the "pedicle probe" perforating the hole. All the result give almost the same pattern where there were sudden increase of hits occur. For the cumulative hits result show the trend is increase for the hits when the perforating process is begin.

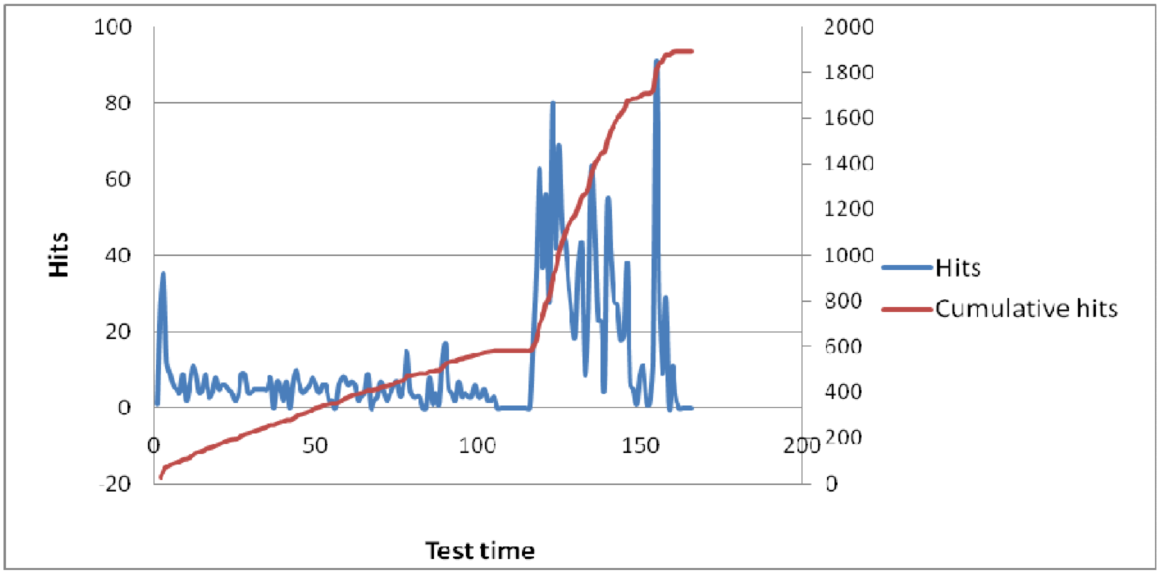


Figure 4.1: Result for the first bone at the hole number 1.

In figure 4.1, at the beginning of the perforation hits graph showed a steady flow without any increment until at the time between 100 to 130 seconds that the sudden increased of hits occur and can be say that the breakthrough of the bone tissue had just happened. Meanwhile, the cumulative hits showed the increasing of activity occur after that.

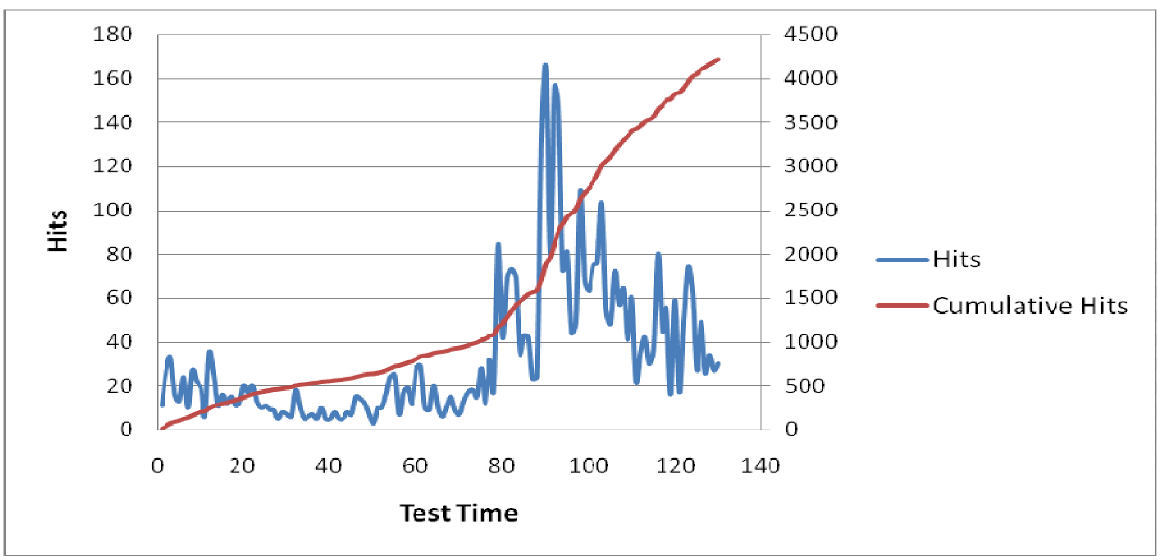


Figure 4.2: Result for the first bone at the hole number 2

For figure 4.2, the sudden increased of hits also occur when perforating process was done. The breakthrough could be happened between timeline at 80 to 90 second and the perforation process take about 129 seconds to be completed.

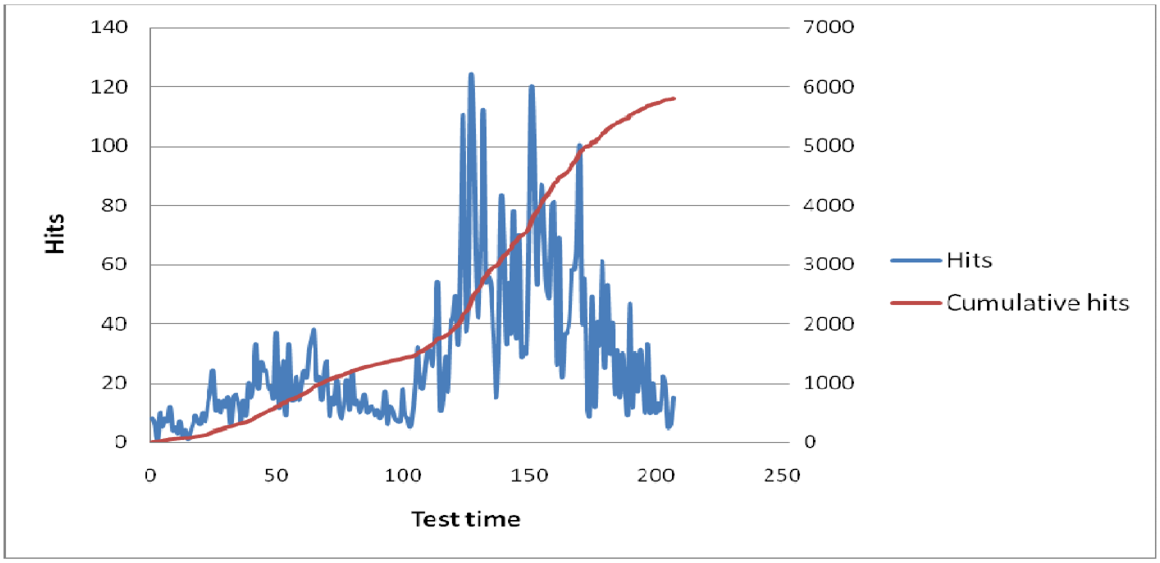


Figure 4.3: Result for the first bone at the hole number 3

Meanwhile, graph hits for hole number 3 show the sudden increase of hits also occur between the timeline at 100 to 125 seconds and much activity happened after the breakthrough if compared before the breakthrough of the bone tissue until the process end at 207 seconds.

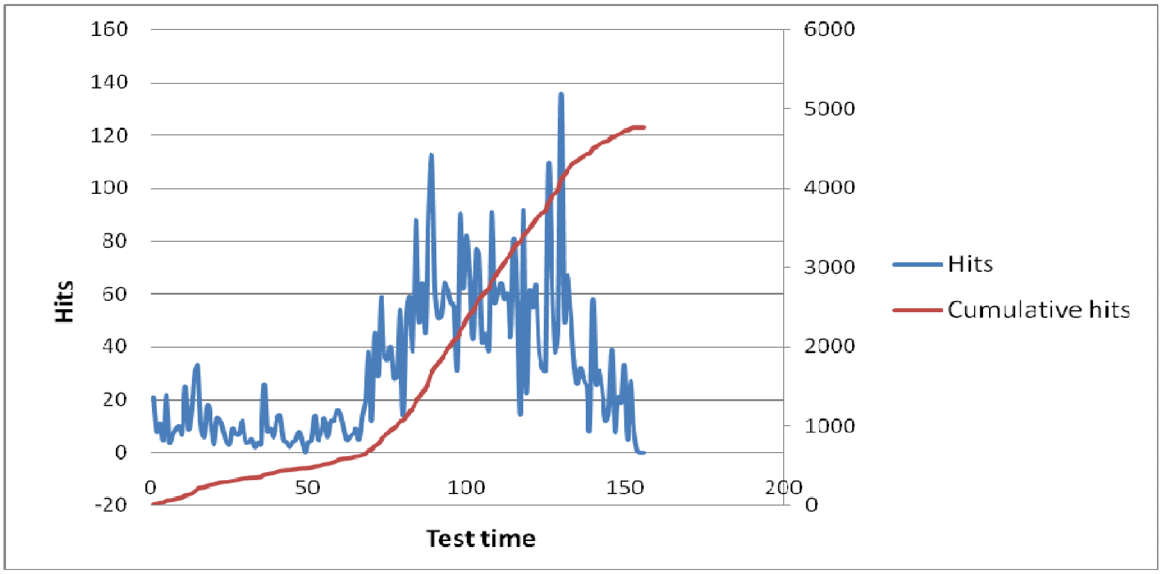


Figure 4.4: Result for the first bone at the hole number 4

Figure 4.4 also show clearly of the sudden increase of the hit happened at the time 65 to 75 seconds and the perforation process continued until 154 seconds.

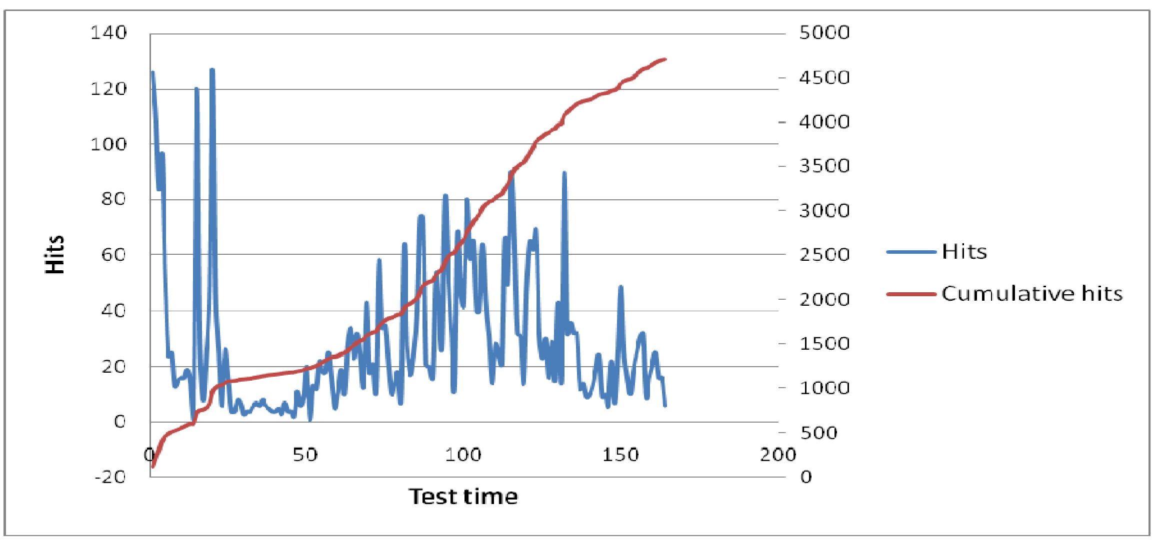


Figure 4.5: Result for the first bone at the hole number 5

There were an increased of hits occur at the beginning of the perforation process as shown in figure 4.5. This phenomena maybe cause by the disturbance from the outside sources. Then, the hits becomes steady until the time of 50 to 70 seconds the sudden increased of hits occur that showed the breakthrough of the bone tissue just happened.

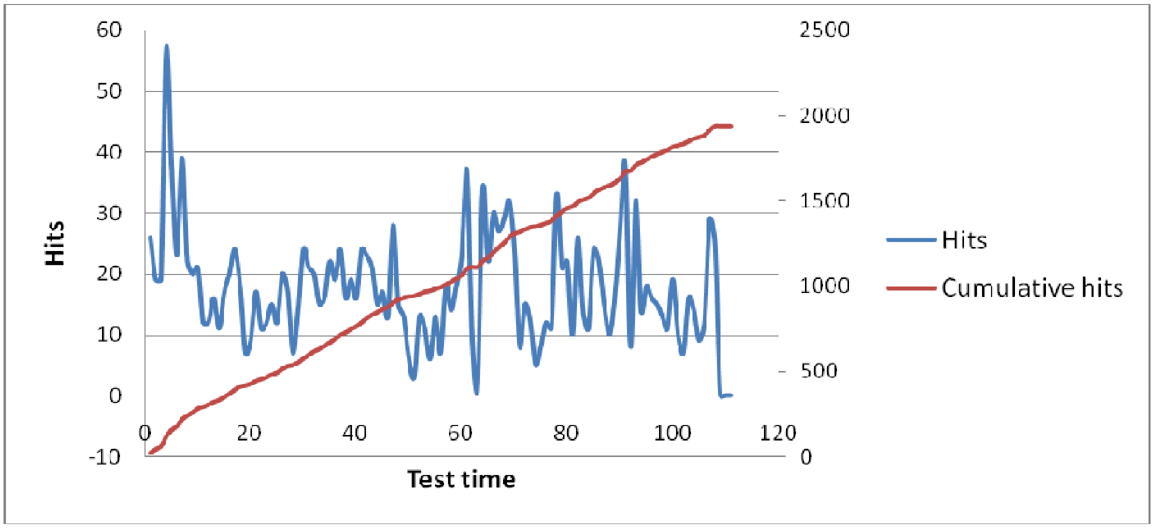


Figure 4.6: Result for the first bone at the hole number 6

As mention before, there were disturbance from outside sources that may occur during the perforation process was done. This was shown in figure 4.6 that the sudden increase of hits could not be detected or seen happened exactly where due to this disturbance. Although there were some error happen during the process, the other result still shown that the sudden increase of hits exactly happened during the perforation process and assumption may be make as the breakthrough of the bone tissue happened where there were sudden increase of hits occur.

4.3 EXPERIMENT ON THE SECOND BONE

As discuss in previous chapter, an indicator had been set up during the experiment for the second bone. This indicator will showed the time of penetration level when the "pedicle probe" reach the interface of bone tissues either hard or soft. In this experiment, about 10 hole had been perforated using the "pedicle probe" and all acoustic emission signal events in the process is being captured using the Acoustic

Emissiom Detector Software. Figure 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16 showed the hits and cumulative hits result for each hole.

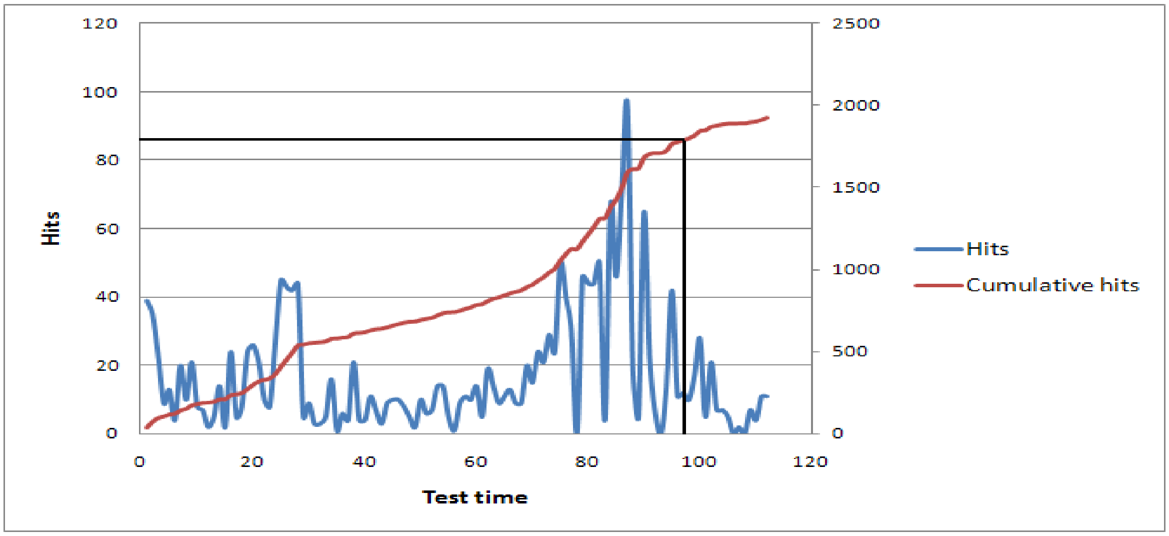


Figure 4.7: Result for the second bone at the hole number 1

In figure 4.7, the penetration level occur at time 96 seconds to reach the interface of the bone tissue at the hole number 1. Meanwhile, for hole number 2 the time taken is 74 seconds as shown in figure 4.8 below.

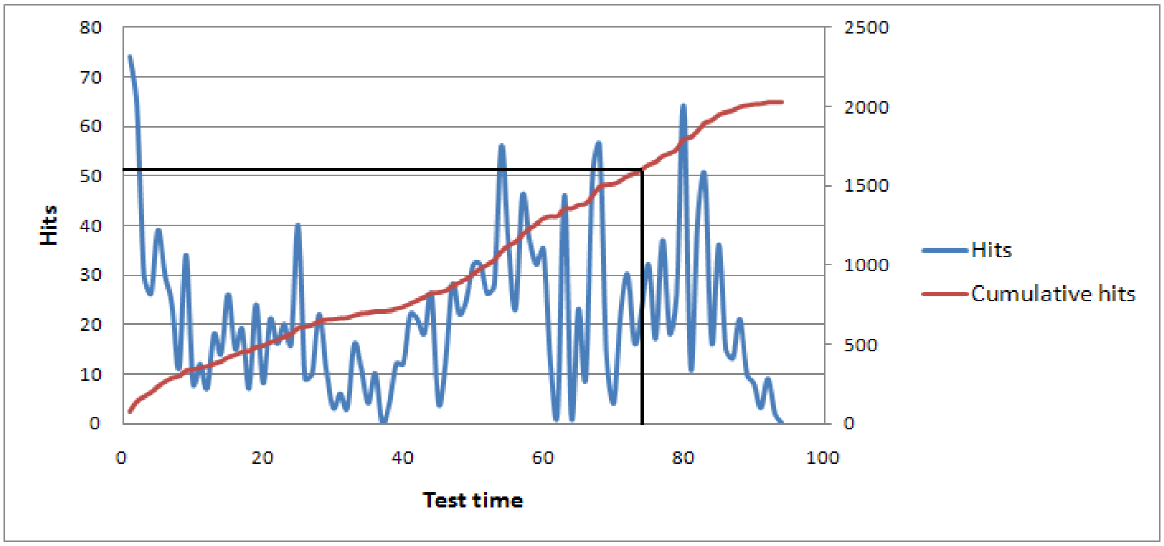


Figure 4.8: Result for the second bone at the hole number 2

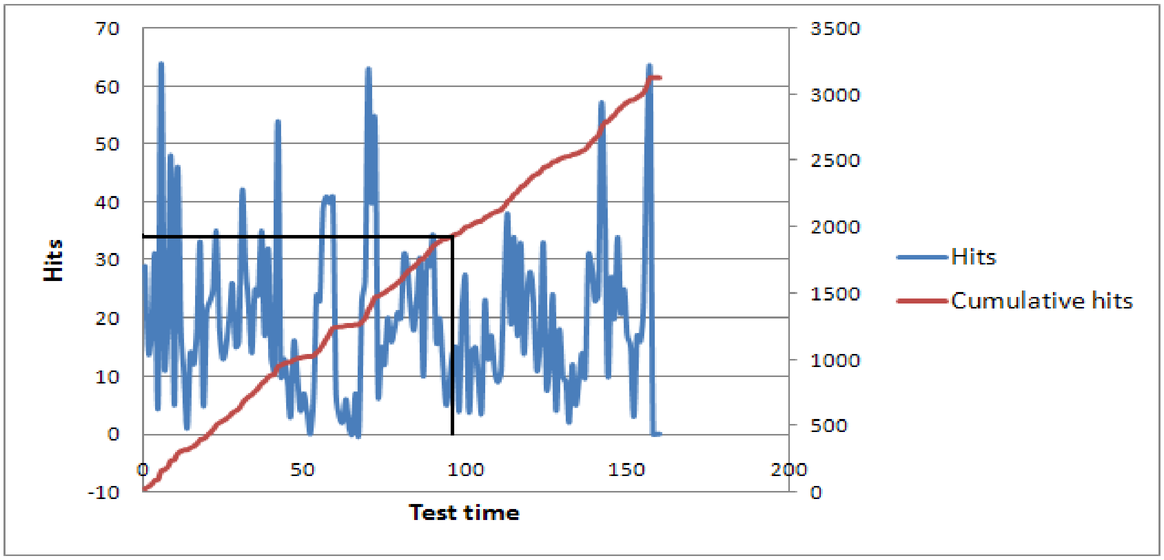


Figure 4.9: Result for the second bone at the hole number 3

For figure 4.9, the penetration level of hole number 3 take time about 96 seconds compare to 98 seconds for hole number 4 as in figure 4.10 to reach the interface of bone tissue.

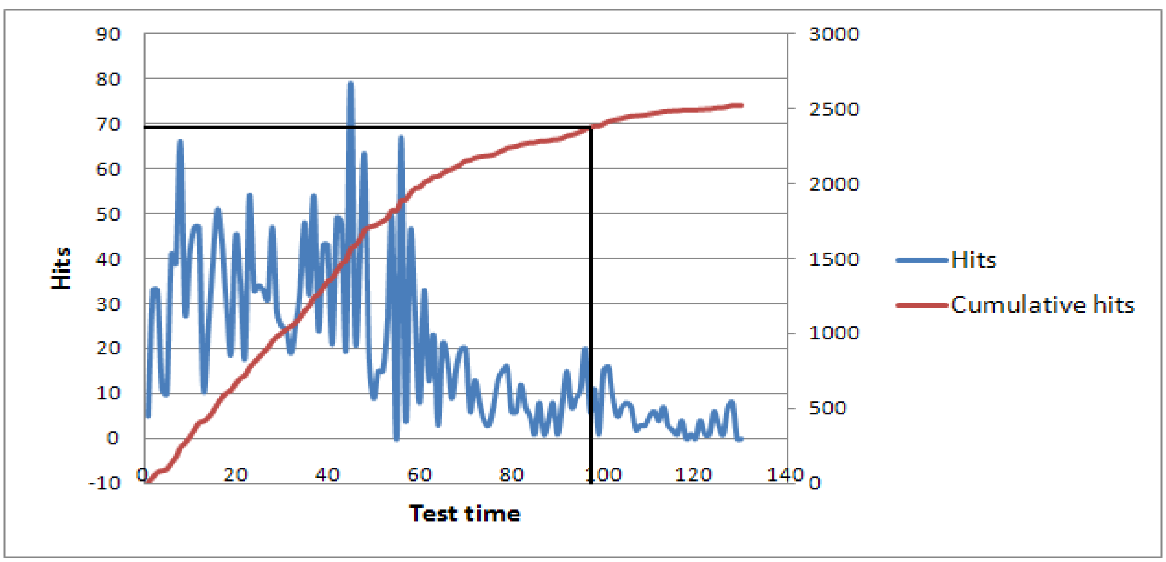


Figure 4.10: Result for the second bone at the hole number 4

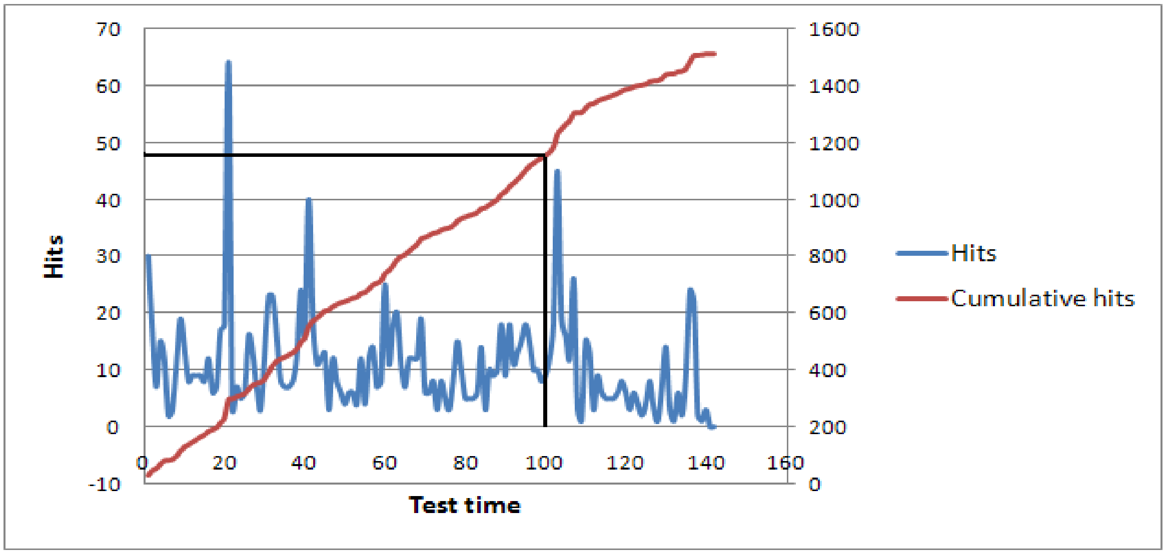


Figure 4.11: Result for the second bone at the hole number 5

Therefore, in figure 4.11 and 4.12, the time taken for penetration level for hole number 5 and 6 is 100 seconds and 105 seconds.

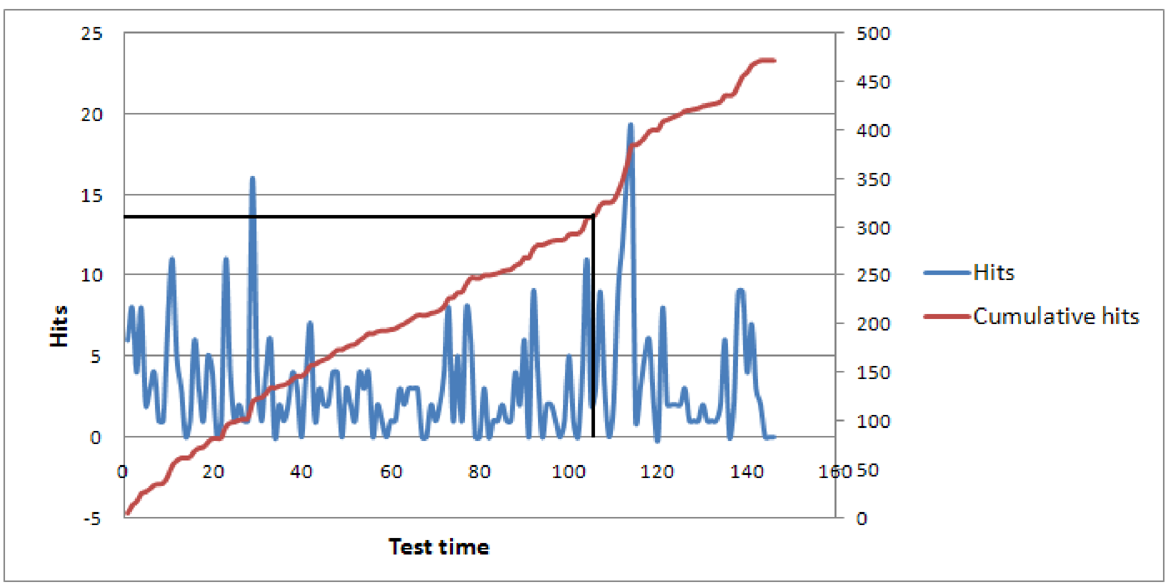


Figure 4.12: Result for the second bone at the hole number 6

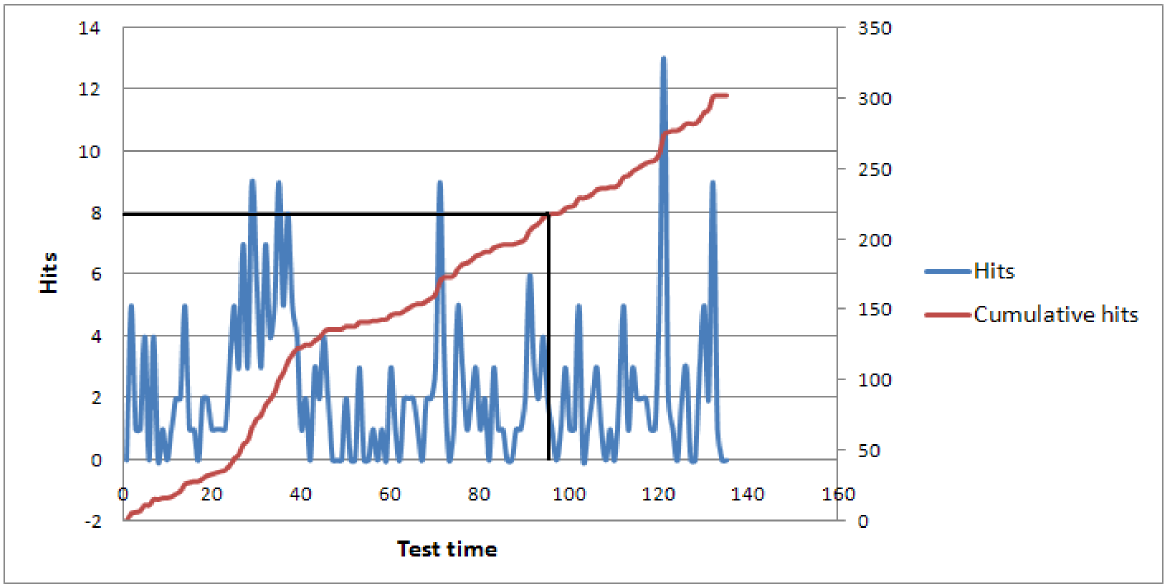


Figure 4.13: Result for the second bone at hole number 7

Time taken for penetration level for hole number 7 and 8 as in figure 4.13 and 4.14 to reach the interface of bone tissue is about 96 seconds and 102 seconds.

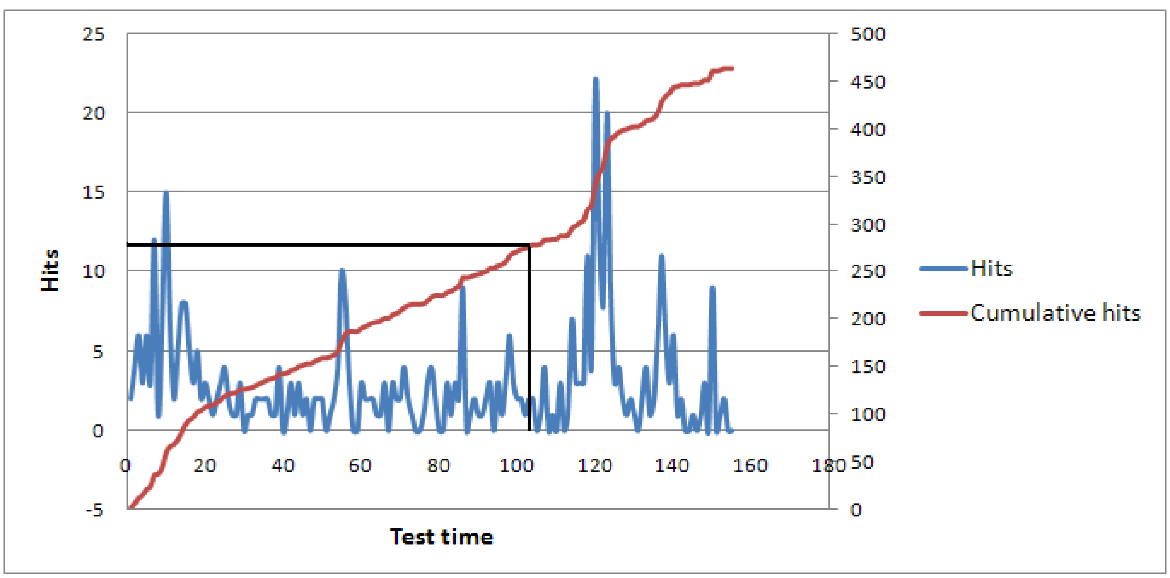


Figure 4.14: Result for the second bone at the hole number 8

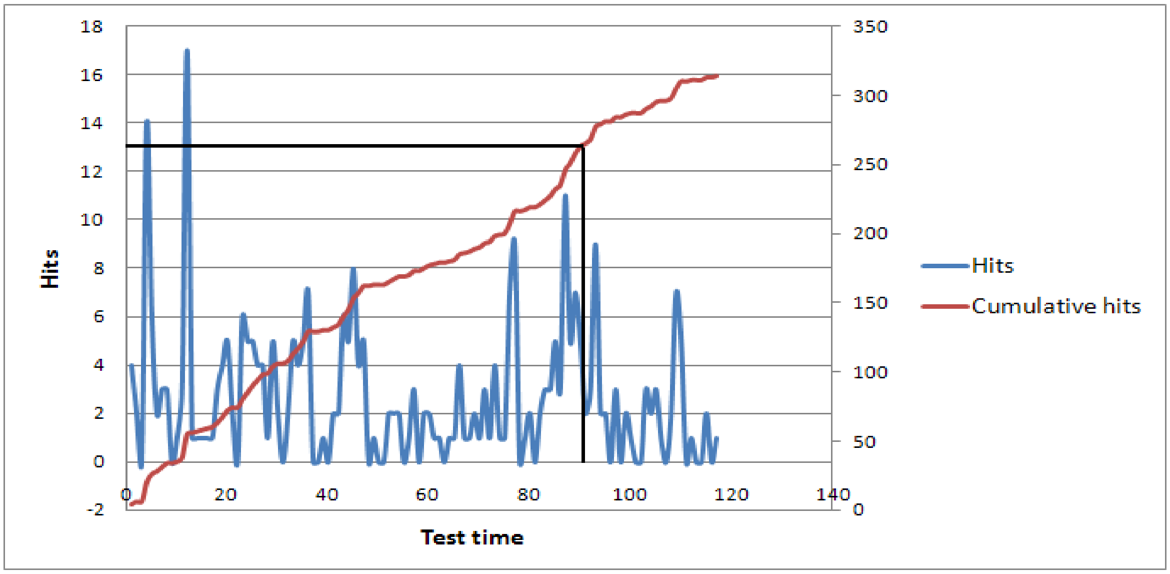


Figure 4.15: Result for the second bone at the hole number 9

Lastly, the time for penetration level for hole number 9 and 10 is about 90 seconds and 98 seconds as shown in figure 4.15 and 4.16.

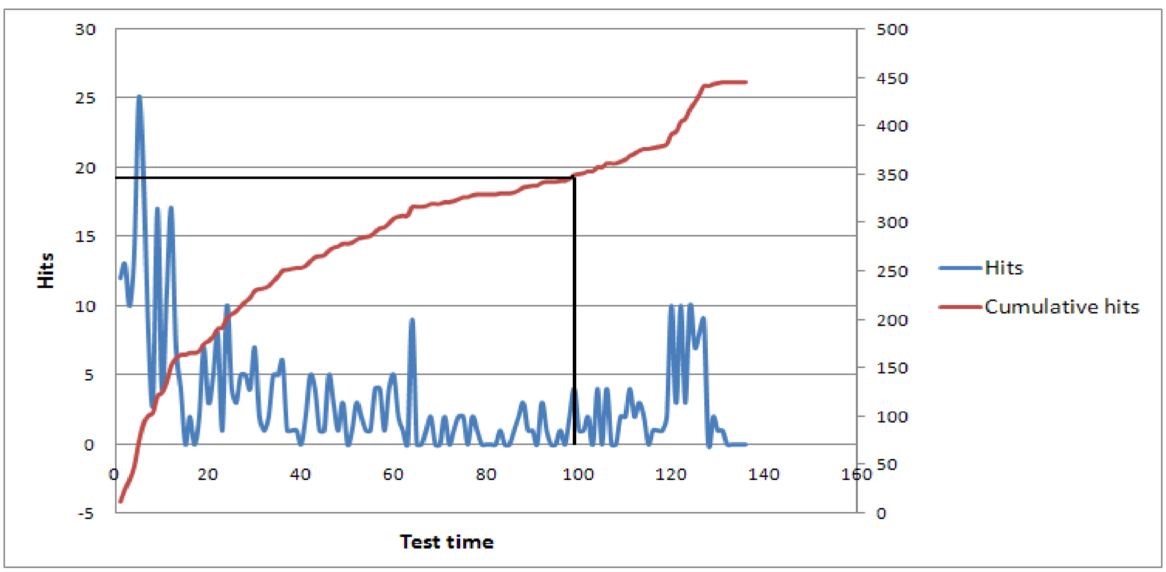


Figure 4.16: Result for the second bone at hole number 10

From previous understanding the time should be same for each hole but the results showed that each hole give quite differents time of penetration level that may due to the composition of the bone tissue itself or the misalignment of the perforation angle that would give long or short time to perforate a hole. This means that the outcome of this experiment is not like what as expected. The time is marked as black line and summarize in table 4.33. The cumulative of hits sometime also show the increasing of hits before reach the time of penetration level in each perforation process that tell us there were more activity when the AE signal events approaching the interface of the bone tissues.

There are some reason that can be related to this activity. Acoustic emission signal events detected more activity due to the rate of deposition of mineral salts and collagen fibers in the bone. Within limits, bone tissues has the ability to alter its strengths in response to changes in mechanical stress. When placed under stress, bone tissue becomes stronger through incerased deposition of mineral salts and production of collagen fibers by osteoblasts (Tortora et al, 2006).

Another reason that can be related to this is aging on bone tissue. In old age, loss of bone through resorption occurs more rapidly than bone gain (Tortora et al, 2006). These factors contribute to the higher incidence of osteoporosis in female because women bone’s generally are smaller and less massive than men’s bones to begin with, loss of bone mass in old age typically has a greater effect in females.

So, more hard the bone tissue there will be more activity of acoustic emissions. When the hardness of bone tissue can be showed by the data as in result of hits that mean it can help the medical practitioner in giving the enough pressure during the hole perforation in pedicle screw fixation procedure. Eventhough, the study had show the result but further study still need to be carried out to get more precisely and accurate data.

Table 4.33: Time of penetration level for each hole

Hole	Time (s)
1	96
	74
3	96
4	98
5	100
6	105
7	96
8	102
9	90
10	98

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

This study had proved that acoustic emissions (AE) technique can be used to evaluate the acoustic emissions signal events in cervical bone during the pedicle screw fixation procedure. The technique offers great opportunity to have new approach of lower cost, safe and precisely method for pedicle screw fixation procedure.

From this study, the first experiment on the first bone has proved that the acoustic emissions signal events could be measured when the “pedicle probe” perforated through the interface of the bone tissues during the pedicle screw fixation procedure. The acoustic emissions signal events had proved the present of the bone’s interface of hard and soft bone tissue when there is sudden increase of hits occur during the perforating process.

Meanwhile the experiment on the second bone give the result with the time marked to estimate where the acoustic emissions signal events detected the interface of the bone tissues. It also tells us that the different hole will have different penetration level and it is depend on the strength of the bone tissues or the pressure given when prepared the hole. The indicator that set up earlier is very important to give the initial reference before perforates the bone. The indicator at the ‘pedicle probe” will act as a guideline while perforated the bone to make sure the real acoustic emissions signal events is captured.

This study use hits and counts in measuring the AE activities or events to show how much activity involved when perforating a bone. These potential results of hits and counts is very important in order to evaluate and study the trajectory path of hole preparation and can be used in further research especially in pedicle screw fixation procedure.

5.2 RECOMMENDATION

In order to get more precisely and accurate result, a proper device should be used instead of using a screwdriver as a tool in the preparation of the hole. For this study it is suggested to get a real pedicle probe as a tool to perforate the bone. The real pedicle probe that used by the surgeon in the pedicle screw fixation procedure is more flexible and easy to operate.

Besides that to get the trends of the results more convincing, thus this study suggested using more bone to get more hole perforated. Besides, time for perforating the bone should be long enough than previous attempted study to see the trend of the hits before and after the interface of the bone tissues. Other than that the most crucial thing need to do before perforating the hole is to make sure the trajectory path or the angle of the pedicle bone has to be correct to unsure when the 'pedicle probe" perforated the bone is right through the pedicle bone and not to perforate the wall of the pedicle. The right angle also would give the time of perforation level may be the same for each hole.

Moreover, the signal events detected also is very important in this study. So, to make the signal more accurate and reliable it is suggested that the location of the AE sensor need to be place at the location that more suitable and easy for AE sensor to captured the acoustic emissions signal events without any disturbance from other outside sources. This is because when the AE sensor is attached to the screw driver it may cause the AE sensor move or not stable due to the movement of the screw driver during the perforating process.

Another important thing that must be considered is the indicator of the penetration level. In this study, the measurement of the indicator is measure from the outside of the bone thickness as shown in previous chapter. It is suggest that in future study CT-Scan or X-ray device should be used instead of conventional method to get the exactly measurement of the bone thickness. CT-Scan will give image in two dimensions and sometimes certain Ct-Scan machine can be arranged into three dimensions image that useful to surgeon while surgery. That means this kind of devices will give more accurate data on the bone thickness compared to the previous method.

The most important suggestion is that the procedure of this study should be done by someone that has the expertise about the pedicle screw fixation procedure. It should be done by practitioners that have the knowledge about clinical surgery and expert on the anatomy of the vertebrae. The study of pedicles in a local population is also imperative before any attempt for cervical fixation using a pedicle screw is initiated. The standard of pedicles screw may not be accommodating for Asian population and that why is become important to firstly measure the pedicle diameter before any pedicle screw is done.

REFERENCES

Bettie, A. G.: Acoustic Emission Monitoring of a Wind Turbine Blade During A Fatigue Test. *Sandia National Laboratory Albuquerque*, NM 87185, American Institute of Aeronautics and Astronautics

Castro, W.H., Halm, H., Jerosch, J., Malms, J., Steinbeck, J. and Blasius, S. 1996. Accuracy of Pedicle Screw Placement in Lumbar Vertebrae. *Spine* **21**: 1320-1324

Gertzbein, S.D. and Robbins, S.E. 1990. Accuracy of Pedicular Screw Placement in Vivo. *Spine* **15**: 11-14

Jerosch, J., Malms, J., Castro, W.H., Wagner, R., Wiesner, L., 1992. Lagekontrolle Von Pedikelschrauben Nach Instrumentierter Dorsaler Fusion Der Lendenwirbelsaule. *Z Orthop* **130**: 479-483

Wei, J. and McCarty, J. 1993. Acoustic Emission Evaluation of Composite Wind Turbine Blades During Fatigue Testing. *Wind Engineering* **17**(6): 266-274

Jemielniak, K. and Kwiatkowski, L. and Wrzosek, P. 1997. Diagnosis of Tool Wear Based On Cutting Force and Acoustic Emission Measures as Inputs To A Neural Network. *Journal of Intelligent Manufacturing* (1998) **9**: 447- 455

Laine, T., Makitalo, K., Schlenka, D., Tallroth, K., Paussa, M. and Alho, A. 1997. Accuracy of Pedicle Screw Insertion: A Prospective CT Study in 30 Low Back Patients. *Eur Spine J* **6**: 402-405

Morris, D. and Sewell, C. and Blevin, N. and Barbagli, F. and Salisbury, K.: A Collaborative Virtual Environment for the Simulation of Temporal Bone Surgery. Robotics Laboratory Gates Building IA Stanford CA 94305- 9010, USA

Methew, M. T. and P Srinivasa, P. and Rocha, L. A. 2008. An Effective Sensor For Tool Wear Monitoring In Face Milling: Acoustic Emission. **33**(3): 227-233

Rao, A.K. 1990. Acoustic Emission and Signal Analysis. *Def Sci J.* **40**(1): 55-70

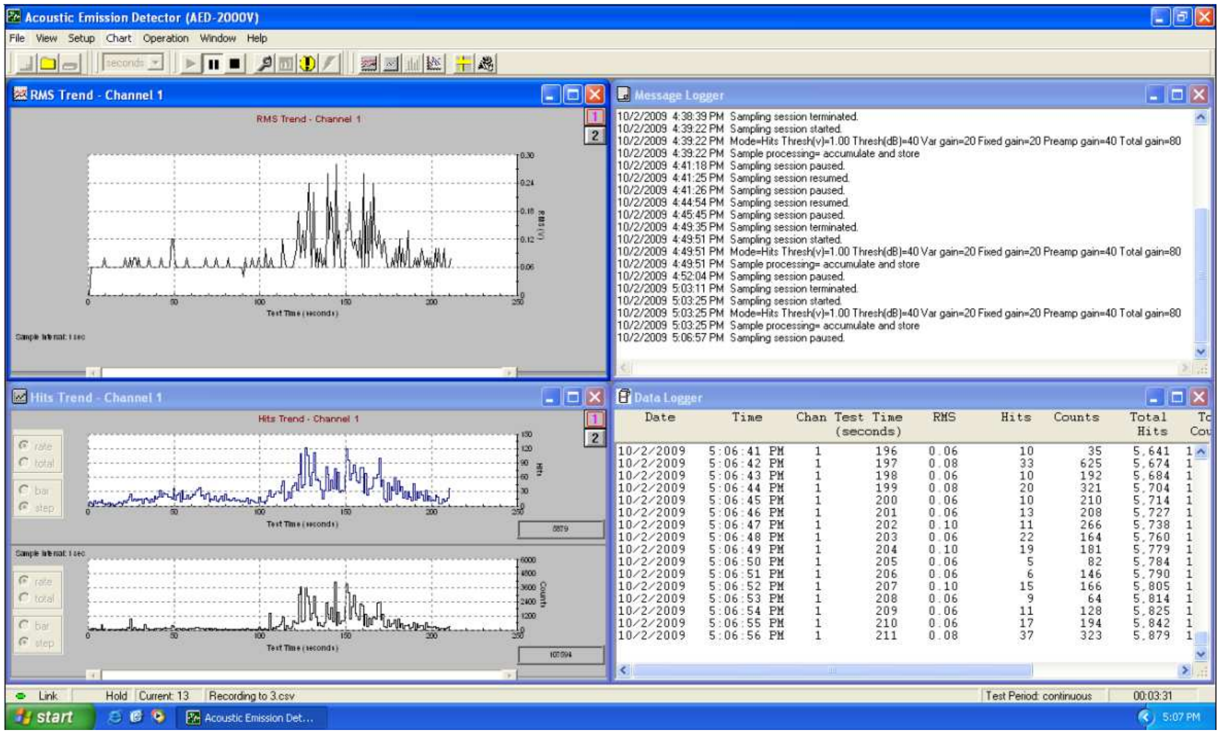
Tortora, G. J. and Derrickson, B. 2006. *Principles of Anatomy and Physiology*. 11th Edition. USA: John Wiley & Sons, Inc.

Yusuf, M. I. and Ming, L. K. and Abdullah, M. S. and Yusof, A. H.: Computerized Tomographic Measurement of the Cervical Pedicles Diameter in a Malaysian Population and the Feasibility for Transpedicular Fixation (2006) **31**:221-224

Zohari, M. H. B. 2008. *Development of Internal Pipe Roughness Classifying Method using Acoustic Emission Technique.* Master Thesis. Universiti Kebangsaan Malaysia, Malaysia.

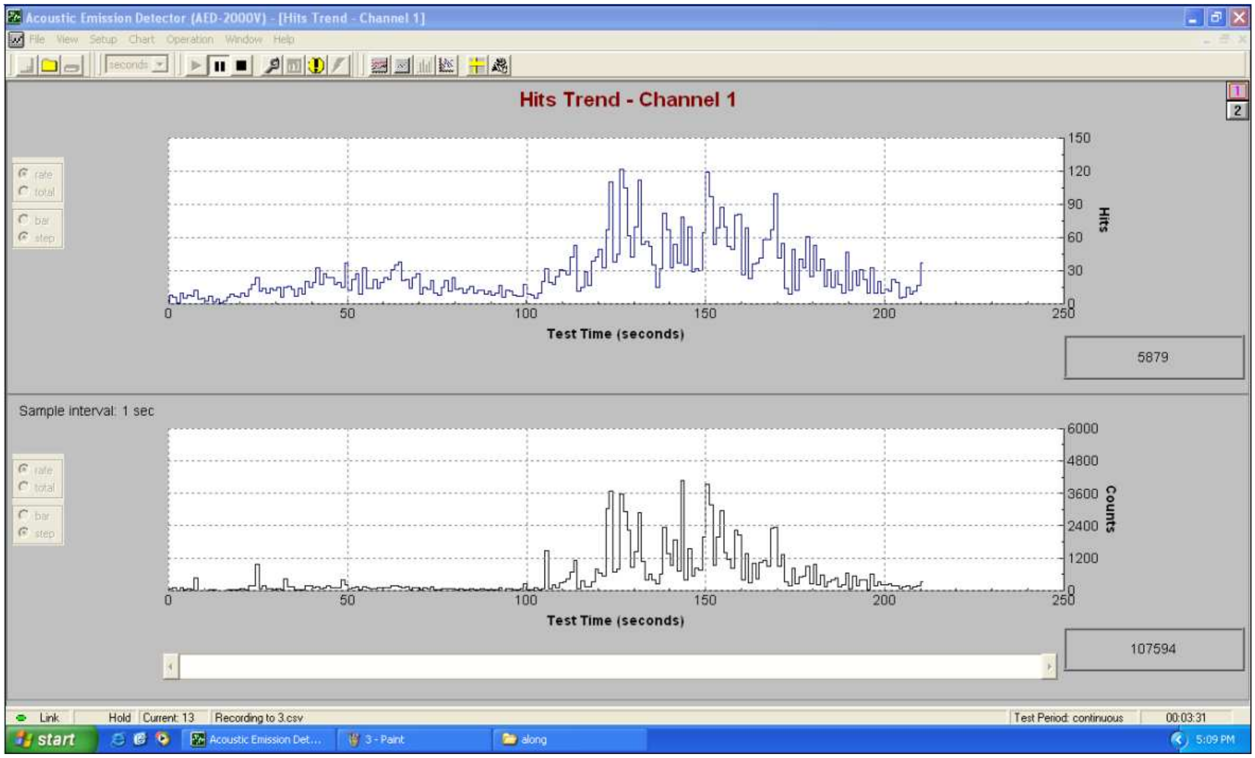
APPENDIX A1

The example of AE signals events that view using Acoustic Emission Detector Software from the experiment on the first bone at the hole number 3.



APPENDIX A2

Example of hits trend graph from the experiment on the first bone at the hole number 3.



APPENDIX B

The example of the test data gained from the experiment on the first bone at hole number 3

Test Time	RMS	Hits	Counts	Total Hits	Total Counts
1	0.06	8	79	8	79
2	0.06	6	91	14	170
3	0.06	1	2	15	172
4	0.06	10	100	25	272
5	0.06	5	40	30	312
6	0.06	8	79	38	391
7	0.06	7	20	45	411
8	0.06	12	470	57	881
9	0.08	4	12	61	893
10	0.06	5	7	66	900
11	0.06	3	5	69	905
12	0.06	7	17	76	922
13	0.06	2	39	78	961
14	0.06	4	12	82	973
15	0.06	1	1	83	974
16	0.06	3	13	86	987
17	0.06	6	50	92	1037
18	0.06	9	41	101	1078
19	0.06	7	25	108	1103
20	0.06	6	26	114	1129
21	0.08	10	66	124	1195
22	0.06	7	32	131	1227
23	0.06	13	196	144	1423
24	0.08	18	170	162	1593
25	0.06	24	960	186	2553
26	0.08	11	60	197	2613
27	0.08	14	174	211	2787
28	0.06	10	54	221	2841
29	0.08	14	85	235	2926
30	0.06	12	46	247	2972
31	0.06	15	65	262	3037
32	0.06	6	27	268	3064
33	0.06	15	422	283	3486

34	0.06	16	136	299	3622
35	0.08	13	129	312	3751
36	0.06	7	32	319	3783
37	0.06	14	31	333	3814
38	0.06	9	48	342	3862
39	0.06	20	170	362	4032
40	0.06	15	171	377	4203
41	0.06	19	99	396	4302
42	0.08	33	156	429	4458
43	0.06	18	85	447	4543
44	0.06	27	99	474	4642
45	0.06	24	187	498	4829
46	0.06	24	107	522	4936
47	0.06	18	113	540	5049
48	0.12	19	125	559	5174
49	0.12	15	381	574	5555
50	0.08	37	232	611	5787
51	0.06	12	68	623	5855
52	0.06	22	97	645	5952
53	0.06	27	136	672	6088
54	0.06	9	36	681	6124
55	0.06	33	150	714	6274
56	0.06	14	92	728	6366
57	0.08	14	82	742	6448
58	0.06	22	70	764	6518
59	0.06	14	103	778	6621
60	0.06	19	106	797	6727
61	0.06	24	92	821	6819
62	0.06	22	104	843	6923
63	0.06	31	195	874	7118
64	0.06	35	172	909	7290
65	0.06	38	147	947	7437
66	0.06	21	107	968	7544
67	0.06	22	141	990	7685
68	0.08	14	38	1004	7723
69	0.06	24	107	1028	7830
70	0.06	27	107	1055	7937
71	0.06	9	16	1064	7953
72	0.06	15	92	1079	8045
73	0.06	13	66	1092	8111
74	0.08	21	138	1113	8249
75	0.06	10	51	1123	8300

76	0.06	8	44	1131	8344
77	0.06	15	57	1146	8401
78	0.06	21	70	1167	8471
79	0.06	11	76	1178	8547
80	0.06	24	69	1202	8616
81	0.08	13	51	1215	8667
82	0.06	14	68	1229	8735
83	0.06	10	44	1239	8779
84	0.06	13	33	1252	8812
85	0.06	16	82	1268	8894
86	0.06	10	25	1278	8919
87	0.06	12	53	1290	8972
88	0.06	12	60	1302	9032
89	0.06	9	51	1311	9083
90	0.04	11	44	1322	9127
91	0.08	8	27	1330	9154
92	0.06	10	49	1340	9203
93	0.06	17	90	1357	9293
94	0.06	6	14	1363	9307
95	0.08	12	76	1375	9383
96	0.06	11	61	1386	9444
97	0.06	8	26	1394	9470
98	0.06	7	40	1401	9510
99	0.08	7	80	1408	9590
100	0.06	18	244	1426	9834
101	0.06	9	33	1435	9867
102	0.06	8	31	1443	9898
103	0.1	5	92	1448	9990
104	0.06	10	31	1458	10021
105	0.06	20	84	1478	10105
106	0.08	32	1461	1510	11566
107	0.06	19	76	1529	11642
108	0.06	18	223	1547	11865
109	0.06	25	122	1572	11987
110	0.06	31	288	1603	12275
111	0.06	30	307	1633	12582
112	0.06	26	428	1659	13010
113	0.12	42	699	1701	13709
114	0.08	53	1129	1754	14838
115	0.06	11	78	1765	14916
116	0.06	15	358	1780	15274
117	0.06	29	153	1809	15427

118	0.06	17	133	1826	15560
119	0.06	39	321	1865	15881
120	0.08	42	806	1907	16687
121	0.1	49	641	1956	17328
122	0.18	33	521	1989	17849
123	0.08	67	3030	2056	20879
124	0.1	110	3676	2166	24555
125	0.14	38	682	2204	25237
126	0.08	45	787	2249	26024
127	0.16	122	3576	2371	29600
128	0.24	105	2915	2476	32515
129	0.16	62	2239	2538	34754
130	0.06	42	865	2580	35619
131	0.22	70	1460	2650	37079
132	0.06	112	2885	2762	39964
133	0.1	54	1091	2816	41055
134	0.06	56	390	2872	41445
135	0.1	52	612	2924	42057
136	0.06	35	401	2959	42458
137	0.08	15	263	2974	42721
138	0.06	32	604	3006	43325
139	0.26	82	2344	3088	45669
140	0.12	67	1368	3155	47037
141	0.2	33	927	3188	47964
142	0.16	54	1891	3242	49855
143	0.06	37	725	3279	50580
144	0.28	78	4093	3357	54673
145	0.1	35	409	3392	55082
146	0.14	70	1543	3462	56625
147	0.06	29	522	3491	57147
148	0.06	32	810	3523	57957
149	0.06	30	751	3553	58708
150	0.14	64	1988	3617	60696
151	0.14	119	3932	3736	64628
152	0.2	97	3189	3833	67817
153	0.12	54	954	3887	68771
154	0.1	69	1981	3956	70752
155	0.12	87	2939	4043	73691
156	0.1	70	1395	4113	75086
157	0.08	52	1151	4165	76237
158	0.14	49	837	4214	77074
159	0.06	80	2221	4294	79295

160	0.26	81	2035	4375	81330
161	0.06	26	410	4401	81740
162	0.18	69	1380	4470	83120
163	0.06	23	302	4493	83422
164	0.2	36	1006	4529	84428
165	0.08	37	417	4566	84845
166	0.24	41	1044	4607	85889
167	0.12	58	1118	4665	87007
168	0.1	58	901	4723	87908
169	0.14	67	2297	4790	90205
170	0.1	100	2354	4890	92559
171	0.08	41	894	4931	93453
172	0.12	55	1350	4986	94803
173	0.1	14	326	5000	95129
174	0.06	9	183	5009	95312
175	0.06	49	829	5058	96141
176	0.06	12	263	5070	96404
177	0.08	40	514	5110	96918
178	0.06	33	550	5143	97468
179	0.1	61	883	5204	98351
180	0.06	25	246	5229	98597
181	0.12	53	967	5282	99564
182	0.06	30	229	5312	99793
183	0.1	40	572	5352	100365
184	0.06	16	141	5368	100506
185	0.08	31	338	5399	100844
186	0.14	15	394	5414	101238
187	0.06	30	476	5444	101714
188	0.06	18	129	5462	101843
189	0.06	10	199	5472	102042
190	0.08	47	651	5519	102693
191	0.06	12	84	5531	102777
192	0.08	30	536	5561	103313
193	0.06	17	175	5578	103488
194	0.1	31	409	5609	103897
195	0.08	22	392	5631	104289
196	0.06	10	35	5641	104324
197	0.08	33	625	5674	104949
198	0.06	10	192	5684	105141
199	0.08	20	321	5704	105462
200	0.06	10	210	5714	105672
201	0.06	13	208	5727	105880

202	0.1	11	266	5738	106146
203	0.06	22	164	5760	106310
204	0.1	19	181	5779	106491
205	0.06	5	82	5784	106573
206	0.06	6	146	5790	106719
207	0.1	15	166	5805	106885
208	0.06	9	64	5814	106949
209	0.06	11	128	5825	107077
210	0.06	17	194	5842	107271
211	0.08	37	323	5879	107594

APPENDIX C

Gantt chart for Final Year Project 1

Project Progress		W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14
1) Get the project title and arrange discussion time with supervisor	Planning														
	Actual														
2) Built the basic knowledge about the project (learning the theory)	Planning														
	Actual														
3) Do research and collect the information from various resources	Planning														
	Actual														
4) State the objective, scope and importance of the study (chapter I)	Planning														
	Actual														
5) Review study of acoustic emission's journals and thesis (chapter II)	Planning														
	Actual														
6) Study of pedicle screw fixation procedure (chapter II)	Planning														
	Actual														
7) A visit to HUSM and had meeting with surgeon	Planning														
	Actual														
8) Study of acoustic emission technique and its applications (chapter II)	Planning														
	Actual														
9) Review of primary research on pedicle screw fixation (chapter II)	Planning														
	Actual														
10) State the overview of the pedicle screw's procedures (chapter III)	Planning														
	Actual														
11) Provide the expected result based on previous research (chapter III)	Planning														
	Actual														
12) Submit draft thesis and log book for final year project 1	Planning														
	Actual														
13) Final year project 1 presentation	Planning														
	Actual														

Gantt chart for Final Year Project 2

Project Progress		W 15	W 16	W 17	W 18	W 19	W 20	W 21	W 22	W 23	W 24	W 25	W 26	W 27	W 28	W 29	W 30
1) Specimens preparation and tools setup	Planning																
	Actual																
2) Perform the pedicle screw fixation procedure (data collection)	Planning																
	Actual																
3) Experiment results analysis (calculation and discussion)	Planning																
	Actual																
4) State initial summary based on experiments performed	Planning																
	Actual																
5) Discuss the analyzed results	Planning																
	Actual																
6) State the possible error during the experiment	Planning																
	Actual																
7) Make conclusion and provide suggestion for improvement	Planning																
	Actual																
8) Prepare the proper thesis to submit	Planning																
	Actual																
9) Final year project 2 presentation	Planning																
	Actual																
10) Summit the thesis	Planning																
	Actual																