Bone Fracture Evaluation Using A-Mode Ultrasound

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Abstract: - This paper presents a novel method of bone fracture evaluation based on A-Mode ultrasound. Utilising the pulse echo method, the attenuation of 1 MHz ultrasound wave propagating through a normal and fractured bone was investigated. Two types of bone fracture were investigated,namely the linear fracture and comminuted fracture. An ultrasound transducer was used to transmit the sound wave to the normal and fractured bone in the body, simulated using a goat's bone encased in gelatine. The transducer then captured the reflected echoes to be viewed via an oscilloscope. The echo signal indicated the time used by the sound wave to travel back and forth from the bone surface. The echo was filtered and the power spectral density was calculated for attenuation measurement based on insertion loss method. The comparison of power spectral density from a normal and fractured bone showed that average signal power on the fractured bone was lower than the normal bone by 4.3dB for both linear and comminuted fractures. Based on the result, the ultrasound signal attenuation showed a potential for use to detect bone fracture; nevertheless, further studies are still neededto determine the type of fractures. The present finding shows the potential of ultrasound in diagnosing bone fracture as an adjunct to x-ray imaging.

Key-Words: -Bone fracture, 1D ultrasound, attenuation

1 Introduction

Bone fracture is a medical condition in which there is an incomplete or complete break in the continuity of the bone [1] as a result of a sudden injury due to high force impact and continuous stress; fragility either due to osteoporosis or certain medical conditions that weaken the bones, such as bone cancer. In clinical setting, radiograph is often performed as gold standard in the diagnostic of bone fracture. In situations where radiographic x-ray alone is insufficient, a Computed Tomographic scan may be performed [2]. However, the use of radiograph in diagnostic of bone fracture is limited to certain group of patient, such as pregnant women due to x-ray radiation risk. Hence, an alternative diagnostic method which is safe, less time consuming, accurate and inexpensive is utterly needed, but in present, has yet to be explored by using ultrasound imaging.

Ultrasound is defined by sound wave having frequency in the range higher than 20KHz [3]. In medical setting, the ultrasound with frequency range of 1 MHz to 20 MHz is used as a diagnostic tool because it can be focused into small, well-defined beams that can probe the human body and interact with the tissue structures to form images.

The current application of ultrasound for bones is mainly for therapy such as healing bone fracture [4-5] and measuring bone mineral density [6]. In general, ultrasound offers real time imaging which is safe from radiation, non-invasive, highly portable and inexpensive imaging modality [1, 7-8]. However, ultrasound is not primarily used for bone imaging because of the high acoustic impedance between the soft tissue and bones that renders difficulties for ultrasound signal to penetrate the bone. In this study, a high power ultrasound wave at a frequency of 1MHz was used to investigate the feasibility of ultrasound wave to penetrate bone for fracture detection by measuring its attenuation level.

ISBN: 978-1-61804-173-9

Ultrasound attenuation occurs when the ultrasound pulse loses energy continuously as it travels through matter. The reduction of the energy is mainly due to the absorption by the material and conversion into heat due to friction [10]. This is unlike x-ray photons, which lose energy in "one-shot" due to photoelectric or Compton interactions with matters. Scattering and refraction interactions also remove some of the energy from the ultrasound wave, thus contribute to its overall attenuation. However, absorption is the most significant factor [9]. The rate at which an ultrasound pulse is absorbed generally depends on the material it passes through, and the frequency of the ultrasound.

The attenuation rate is specified in term of an attenuation coefficient in the units of decibels per centimetre. Since the attenuation in tissue increases along with frequency, it is necessary to specify the frequency when an attenuation rate is given.

2 Materials and Method

Two goat's bones were used for this experiment. The bones were cleaned and bleached with hydrogen peroxide to remove any bad odour as shown in

Fig.1. The bones were also encased in gelatine to simulate flesh, as shown in
Fig.2. The speed of sound in gelatine is similar to soft tissues at approximately 1540m/s. Each bone in Fig. 2 was used twice in the experiment; firstly as normal bone sample and then secondly as fractured bone sample. The fracture was simulated by applying appropriate force with blunt tool. As shown in

Fig.1, bone A was given a linear fracture, which was a fracture parallel to the bone's axis, meanwhile bone B wasgiven comminuted fracture, which was a fracture broken into few parts. The different fractures tested were used to observe whether the types of fracture can be determined from the attenuation of ultrasound signal.

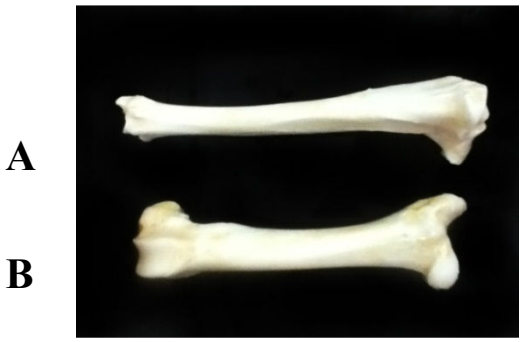


Fig.1 Bleached normal bone sample


Fig.2 Bone encased in gelatin

The experiment set up consisted of a 5077PR Manually Controlled Ultrasound Pulser Receiver unit, Olympus-NDT, Massachussets, USA. The unit was set to deliver 400V of negative square wave pulses at the frequency of 1MHz to an ultrasound transducer with peak frequency at 1MHz. The transducer was used to transmit and receive the ultrasound wave in the transmission mode setting from the z direction. The pulser receiver was connected to a digital oscilloscope, and a laptop for display and storage purposes. Fig.3 shows the block diagram of the experimental setup.

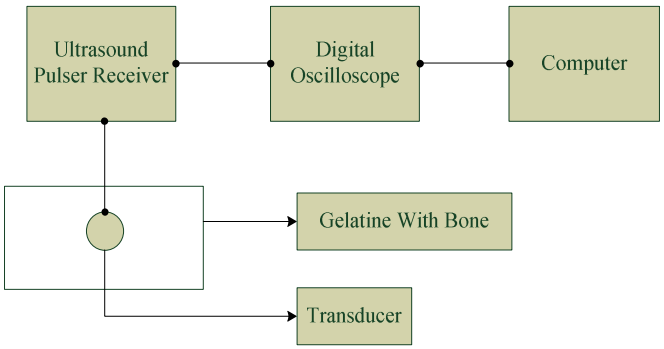


Fig.3 Top view Block diagram of experiment setup

Data collection was done by taking 20 echo signals along the axis of the bone at an interval of 0.1cm as shown in Figure 4. The transducer was placed on the top surface of the gelatine. After the first echo was recorded, the transducer

ISBN: 978-1-61804-173-9

was moved forward to 0.1cm and the data collection was repeated. The reading was taken 25 times for bone A and 20 times for bone B.

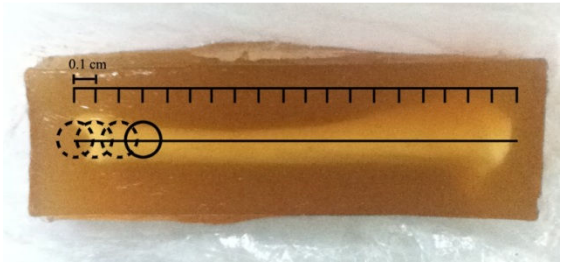


Fig.4Scanning steps of ultrasound transducer

Collected data were categorized into 2 groups. Group 1 was labelled as normal bone and group 2 was labelled as fractured bone.Table 1 below summarises the grouping.

Table 1: Bone sample grouping

	Normal	**Fractured**
Bone A	No fracture	Linear fracture
Bone B	No fracture	Comminuted fracture

The ultrasound signal was first recorded from normal bone A and B. After completing the normal bone group, the bones were fractured and another cycle of ultrasound signal was recorded for the fractured bone group. Each echo signal was stored in a computer as CSV file to be analysed in MATLAB.

Later, the ultrasound data was further processed to calculate the power spectral density of the signal in Matlab. The processing steps involved the determination of frequency content of an ultrasound waveform via frequency decomposition to find its attenuation in each tissue group and gel. This analysis stage involved a total of 50 ultrasound echo signals for bone A and 40 ultrasound echo signals for bone B as described previously. Firstly, the ultrasound signal in time-domain was converted into frequency domain using the Fast Fourier Transform (FFT) algorithm. Following that, the signal was filtered and the power spectral density was calculated with the following formula: Given a signal X with N sampling, its power spectrum can be calculated as follows for double sided spectrum.

$$Powerspectrum S_{AA} = \frac{FFT(X).FFT^*(X)}{N^2} \quad (1)$$

where FFT*(A) denotes the complex conjugate of FFT(A). To form the complex conjugate, the imaginary part of FFT(A) was negated. The power values are in squared amplitude, therefore they were converted to dB scale which was more suitable to view wide dynamic ranges. The following formula can be used for conversion:

$$P(db) = 10\, log_{10} S_{AA} \quad (2)$$

Once the power densities for both normal and fractured bone were determined in decibel unit, the attenuation scale was calculated by subtracting the signal's power in dB for normal bone with the signal's power in dB for fractured bone. The equation for the attenuation is as follows:

$$Attenuation(dB) = P_N - P_F \quad (3)$$

where P_N is the signal's power for normal bone and P_F is signal's power for fractured bone.

The analysis was further done using the statistical approach. The power readings were loaded into Microsoft Excel to perform the statistical analysis of mean and standard deviation for all the groups as mentioned in Table 1.

3 Result

The data analysis was done to calculate the power spectral density of the signal. A typical echo signal as recorded during the experiment is shown in Figure 5.

ISBN: 978-1-61804-173-9

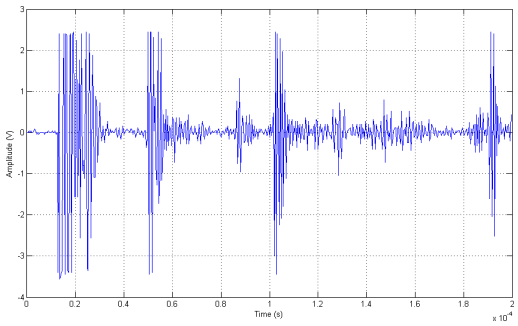


Figure 5 Echo signal from normal bone A

From the signal, the identification process was done in order to determine the actual source of each echo signal. Each echo distance was measured from the gelatine to see the reflection sources. The signal identification for the echo signal in Figure 5 is shown in Figure 6. Signal identification was needed to crop the necessary signal.

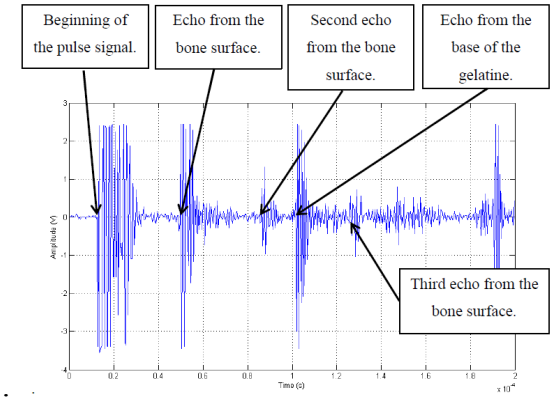
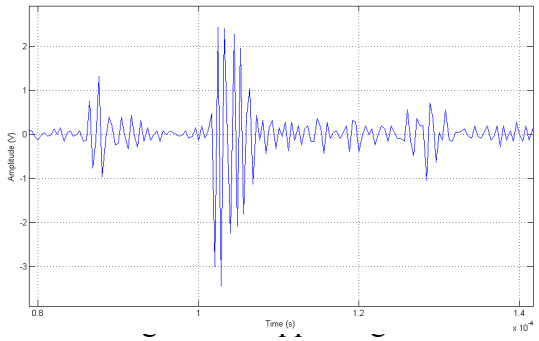


Figure 6 Echo signal identification

500 ultrasound samples were obtained during the data collection for each echo signal at the sampling frequency of 2.5MHz. However, the information was too long, therefore the signal was cropped so that only the necessary echo signal would be taken for power calculation. Figure 7 shows the extracted signal based on the echo signal in Figure 6.



The cropped signal was then fed through a FFT algorithm so that analysis could be done in frequency domain. The signal was then filtered using a 10^{th} order Butterworth low pass filter with a 3dB cut-off frequency of 1.1MHz. Butterworth filter was used because it would not cause ripples at the pass band although its roll-off rate was slower. To overcome that problem, a 10^{th} order was chosen for the filter.

The spectral density of a wave, when multiplied by an appropriate factor, will give the power carried by the wave, per unit frequency, known as the power spectral density of the signal. PSD describes how the average power of a signal is, distributed with frequency. Based on an echo signal, its amplitude spectrum can be obtained using the FFT algorithm. Using the amplitude spectrum data, the power spectral density was calculated.

Using Equation 1 and 2 for calculating power spectral density, the graph below,as shown in Figure 8,was plotted. From there, the power of the signal at 1MHz could be retrieved.

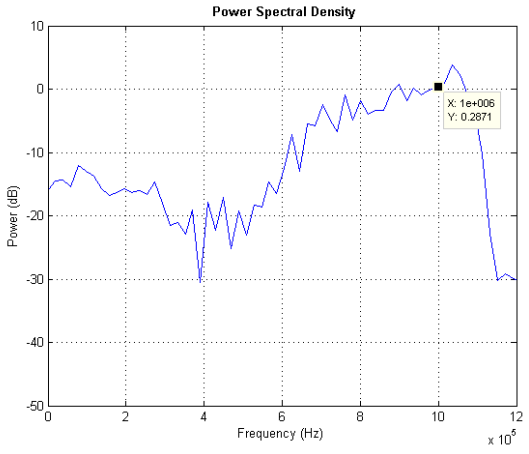


Figure 8 PSD of the filtered signal

ISBN: 978-1-61804-173-9

Table 2 summarises the mean and standard deviation for each group and the attenuation of fractured bone.

Table 2: Experiment result in the form of statistical data

	Bone A	Bone B
Normal (dB) Mean±stdev	-2.000±2.712	-9.419±3.625
Fractured (dB) Mean±stdev	-6.325±5.679	-13.807±5.549
Attenuation (dB) Mean±stdev	4.325±6.123	4.388±7.096

The result shows that the normal bone A and bone B had different signal power to begin with. Bone A had higher power at -2 dB whereas bone B had -9.419 dB for its mean value. This significant difference of values for normal bones was due to the effect of the bone placement itself in gelatine. The placement for bone A was set nearer to the surface of the gelatine compared to bone B which was placed slightly deeper into the gelatine. The ultrasonic signal might have been weakened through the absorption by the gelatine where the ultrasound signal through gelatine B suffered more absorption compared to gelatine A as the signal needed to travel deeper. This situation can be used to relate the attenuation, for example, scanning a fat person who has thick layers of fat or muscle compared to a skinny person with thin layer of flesh. A higher attenuation can be observed during the scanning onto the fat person.

The standard deviation for both normal bones had no significant differences. This slight difference might be caused by the structural difference between bone A and bone B. The difference in shape and size should cause different reflections and scattering patterns for each bone [11].

Looking at the result of fractured bone, it could be clearly seen that the mean power value for both bones had decreased significantly. Absorption still played the main role for the signal attenuation but the scattering and reflection processes of signal had increased due to the fractured state of the bone. Fractures introduced gaps and spaces into the bone which would cause the signal to penetrate even deeper. This would then increase the absorption process and attenuate more signals. Apart from that, fractures also caused substantial changesonto the structure of the bone. The alignment of the bone with the surrounding soft would no longerbe the same. This abnormal placement of fractured bone caused scattering and reflection that was directed away from the transducer, hence less signal would be returned.

As seen in the result, fractures had caused the signals to get weaker. However, based on the attenuation, the mean power value for both bone A and B were almost the same at 4.3dB, even though the two bones had different types of fractures.In other words, PSD evaluation alone is less accurate in evaluating the types of fracture and a more complex algorithm is necessary for fracture differentiation and future studies will be focused on solving this issue.

One possible explanation could be because the overall gaps and space produced in both fractures might be the same although the fracture classification was different. This would eventually produce the same attenuation although the patterns of absorbing, reflecting and scattering signals were unique to each bone.

4 Conclusion

Based on the research done, it was proved that ultrasound attenuation can be used for bone fracture evaluation. Compared to other available evaluation methods such as x-ray, ultrasound does not use ionising radiation; it is low cost and highly portable. The author used a single element ultrasound transducer along with an ultrasound pulser receiver for signal transmission, and data collection was made via a computer using a digital oscilloscope. The sample used comprised two types of fracture, which were linear and communited fracture. The required signal was then extracted, filtered and the signal's power was computed. The power between the normal and fractured bone

was compared to get the attenuation value. Based on the result, there was a significant amount of attenuation between the normal and fractured bone. Therefore, it has been proven that the attenuation of the signal can be used for fracture evaluation. However, the attenuation values for both type of fracture were the same at 4.3dB. This shows that PSD assessment alone is insufficient to determine the fracture type. Therefore,further research should be done, utilizing a more effective method to determine the type of fracture based on the one dimensional ultrasound.

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