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ORIGINAL ARTICLE

Detection and identification of subcutaneous defects using ultrasonic waves in reflective test

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ABSTRACT – Non-destructive ultrasonic evaluation is one of the methods used for inspection in mechanical engineering. This method has diverse applications in various fields, including industry and medicine. The main purpose of this research is to identify a subcutaneous defect with ultrasonic waves. This is done by sending ultrasonic waves into the skin tissue and receiving backward echoes, simulating them using a software, and calculating the time difference using the speed of sound. In this research, the behavior of longitudinal and transverse waves is investigated in collisions with a defect by describing the genesis and application history as well as the principles and definitions of ultrasonic waves. In the test, first, the method of identifying the subcutaneous defect is explained. Then, the dimensions and stiffness of the defect are determined by analyzing the information obtained from the location. Using the 3.5-MHz probe, the defect was detected at a distance of 1.8 mm, indicating a high level of reliability compared to the sonography imaging device. This was while the 10-MHz probe failed to detect the defect just near the skin surface. The results confirm the choice of this method as a suitable method for detecting the subcutaneous defect.

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INTRODUCTION

Sound is one of the most recognized natural phenomena for humans. Not only humans but even other creatures use this physical phenomenon in their daily activities. Sound is produced by vibrations of an audio source. The existence of a material environment (particles of matter) is necessary for the propagation of sound waves. Therefore, ultrasonic does not propagate in a vacuum that there are no material particles. The source vibrations oscillate the adjacent particles, and also these particles oscillate their adjacent particles, and the vibration of the material is progressed continuously. The transfer of vibrations from the particle to other particle is actually a sound wave that is released in the environment. In other words, the propagation of sound, and consequently ultrasonic, is the transfer of energy in the environment due to the oscillation of the particles of matter.

In 1826, Swiss scientist Jean-Daniel Colladon of the church bell used in his experiment to measure the speed of sound. Colladon did his experiment in Lake Geneva and found that sound in the water was moving faster than air [1]. In his experiment, at the same time the gunpowder was ignited, the bell rang underwater. A flash of the gunpowder Combustion 10 miles away was compared with the sound coming from the bell underwater and heard from a device like a trumpet. Despite the incomplete instrument, he determined the speed of sound in water at 1435 m/s [1, 2]. In 1842 Christian Andreas Doppler, an Austrian mathematician and physicist showed that the frequency intensity of a wave depends on the speed of the source [3]. This discovery was known as the Doppler Effect [2].

In 1880, curie brothers in Paris discovered the crystals that could convert ultrasonic energy into electrical energy, and its reverse effect known as the piezoelectric effect that converts electric energy to ultrasonic energy in the same crystals was discovered by Gabrial Lippman in 1881 [4]. The first ultrasonic instrument called Hydrophone was constructed by French physicist Paul Langevin and colleagues to detect submarines in 1917 [5]. The hydrophone sound converter includes a combination of the thin crystals of quartz among two metal plates with a resonance frequency of 150000 Hz [1]. In the early 19th century, Lord Rayleigh discovered surface waves of Rayleigh. These waves are used in many non-destructive sound tests [6].

In addition to ultrasonic application in industry, medicine is another field that uses sound waves. Due to the use of radiograph rays on the human body with side effects, the use of ultrasonic is very important in the diagnosis and treatment of diseases in the medical field. Therefore, the use of ultrasonic waves requires full recognition of the sound, manner of the sound and how to use it. Today, the diagnosis and in some cases the treatment of diseases, using ultrasonic waves is very much considered as a safety feature and as a novel research. Also, many glands and tumors can be detected by measuring the thickness and their layers.

One of the organs of the body is the skin that covers entire of the body surface and has a surface area of about 2 square meters. Since the skin is the outermost organs in the body that is in contact with the surrounding area, hence, it faces a lot of dangers. Therefore, in order to prevent possible injuries or treat them, it is necessary to fully recognize this organ and

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identification methods of these injuries and ultimately the correct treatment. There are different ways to identify skin problems. One of the ways to detect skin defects and get a lot of information is the use of ultrasonic to detect skin defects with or without causing the least skin defects from the type of damage to the skin. Using ultrasonic waves and investigation of skin properties, in addition to detecting and identifying surface defects, also the subcutaneous defects can be detected that are hidden from direct view.

Alongside all human achievements, ultrasonic was a valuable invention that played an important role in medical science to diagnosis and detects many abnormalities with ultrasonic wave. Images of fixed and moving tissues are made by using ultrasonic waves and body sound properties.

The section images of the body tissues are produced in some degrees of gray color by the pulse-echo method. Sound pulses are sent directly to the body. In this path, the tissue depth of the pulse-echo generator is determined from the interval between sending and echo, and the gray color of the image is determined by the pulse-echo amplitude. In addition to the two-dimensional images of the body, information such as anatomy, volume and movement of organs, blood velocity, and 3D images are obtained.

Ultrasonic imaging of the skin has been used for about 30 years. The first studies on the use of ultrasonic in cancer treatment in 1933 and the first report on its use in the treatment of physiotherapy were published in 1939. In 1946 ultrasonic with X-rays was studied in 1967 with chemotherapy [7]. William Fry and Russell Meyers at two different universities used ultrasound in patients with Parkinsonism to destroy parts of the basal ganglia and performed craniotomies [1]. In addition, Frye worked on ultrasound standards, which were very necessary. Ultrasound power was used in physical medicine [1]. The use of ultrasound in medical tests by Karl Theodore Dussik in the late 1980s made him the first known physician to use ultrasound in medical diagnosis [1, 8, 9].

Dosik and his brother tried to find the location of the tumor and brain ventricles by measuring ultrasound scans in the skull. In one article in 1942, Dussik published the first results of his experiments. Supplementary results were presented in 1947 after World War II. They introduced their technique as "hyperphonography" [1]. Using two transducers mounted on both side of the head and producing pulses of 1200 kHz and time intervals of 1/10th seconds, they were able to produce reflective images of the brain ventricles. They called this work their "ventriculograms". By placing two transducers and the top of the head in the water, they were able to create a proper connection between the transducer and the head and record changes in sound speed on heat-sensitive paper in dark and bright spots. This was the first scan of the human body [1]. Although, their device seemed sophisticated. But the images that were created were very basic and contained 2-D rows. They proved that ventricles imaging can be done to identify brain tumors. It is also possible to use low-intensity ultrasound to image body tissues [1, 10, 11, 12].

In 1952, John Wilde and John Reid published the paper: "Application of Echo-Ranging Techniques to the Determination of Structure of Biological Tissues" [1]. At the time, they developed a B-Scan tool that could be hand-held, and were able to detect breast tumors by sweeping [1]. In May 1953, they used a 15 MHz frequency to produce real-time images in their own way [1]. Also they invented method "echography" and "echometry", suggesting the quantitative nature of the investigation [1]. Plaqueini also studied the effects of age-related skin changes in different areas of the skin in 1999. He used ultrasonic waves to measure skin thickness in his research [13]. Hamid et al. in 2000 showed that if the thickness of the cow's skin can be measured, this thickness in different areas of the body can be a sign of its lactation [14]. Brown et al. measured the thickness of sheep skin in different areas of the body using ultrasonic waves in the same year and compared the thickness to the size of the caliper [15]. One year later, Wiesenthal and colleagues used ultrasonic waves at 20 MHz to measure the speed of these waves in skin tumors and calculated the rate as a sign of tumor characteristics [16].

Siemens Wortsman and Jacobo Wortsman used ultrasonic to detect local skin defects. Ultrasound improved their performance by 23.7% [17]. Harold Alexander and D.L. Miller (1979) determined the thickness of the skin using ultrasonic pulses and compared the results of ultrasonic echo with radiology [18].

Jerome Christian used ultrasonic in the treatment of patients with rheumatoid arthritis in 1953 [1]. In 1940, H Gohr and Th. Wedekind in his article "Der Ultraschall in der Medizin" introduced the use of echo-reflection method. They believed that this method could detect tumors, abscesses or exudates [1].

In 2003, Mueller et al. studied “Epidermal Thickness at Different Body Sites: Relationship to Age, Gender, Pigmentation, Blood Content, Skin Type and Smoking Habits”, and used high-frequency ultrasonic in their measurements [19]. Larnett et al. measured the thickness of the skin in 2007 in three different areas of the body and in three ethnic groups: Caucasian, Asian and Black ranges using high frequency ultrasonic waves [20].

One of the applications of skin thickness determination for to perform therapeutic functions such as drug delivery or diagnostic monitoring of physiological parameters. In 2016, Hamid Basaeri et al studied Acoustic waves as a method for delivering power through human skin and the human body for bio-implantable or implantable medical devices (IMDs) [21].

In 2018, YujiaYang et al. investigated the performance of ultrasound shear wave elastography (US-SWE) in the assessment of skin (the dermis) stiffness in patients with systemic sclerosis (SSc). They measured the thickness and elastic modulus of the skin were measured using US-SWE at 6 sites (the bilateral middle fingers and forearms and the anterior chest and abdomen) in 60 SSc patients and 60 healthy volunteers [22]. Also in 2019, T.J.S.Van Mulder and colleagues published an article entitled "Skin thickness measurements for optimal intradermal injections in children." In this article, they allow the maximum penetration depth and needle characteristics for the development of a platform of medical devices suited for intradermal injection, VAX-ID® and to ensure an accurate ID injection injection in children, the epidermal and dermal thickness at the proximal ventral and dorsal forearm (PVF & PDF) and at the deltoid region in children aged 8weeks to 18years were assessed [23]. In the latest research in 2020, Dale R. Wagner and colleagues studied the measurement of subcutaneous fat thickness using state A and B tests. They published the results of comparing the two modes in an article entitled "Comparison of A-mode and B-mode Ultrasound for Measurement of Subcutaneous Fat" [24].

In this study, ultrasonic waves are used to measure and accurately determine the thickness of the skin layers and the subcutaneous defect. Therefore, in this study, all the factors influencing this measurement are studied to determine the most appropriate type of ultrasonic waveform and the best signal processing method required for the highest accuracy. Therefore, first, must be determined the type of ultrasonic wave that is suitable for measurement. Then determine the frequency and type of probe required for measurement. Measurement is performed by identifying the above variables. After obtaining ultrasonic signals, the best signal processing method with high precision must be specified and used, and finally, the measurement uncertainty amount is determined. Therefore, this research is aimed at identifying subcutaneous defect and measuring the location of the occurrence defect of underlying skin, the development of the defect and the severity or progression of the disease, and the extent to which the disease has occurred on the skin.

According to the studies, this study will investigate the development of artificial flaws in cow or sheep skin and the use of probes and ultrasonic waves to analyze ultrasonic contact reflections, in order to determine the best type of probe and appropriate parameters for ultrasonic application. Experimental experiments on the skin have been carried out and the results have been discussed.

MATERIALS, EQUIPMENT, AND TESTING METHODS

In this study, there was no possibility of using the human sample in the laboratory. Therefor a sample of cow skin and sheepskin with fat and a vertical longitudinal wave contact probe with central frequency of 3.5 MHz of the SL64-10 model with the serial T027496 manufactured by the Sonatest company and a 10-MHz probe of the C544 model with the serial 698270 by Panametrics company, was used. These probes are transceiver type, which stimulated by a 5072PR pulser- receiver device, manufactured by the Panametrics Corporation and is set in accordance with Table 1. The received signals transmitted to a computer by an analog to digital converter. This converter made by Gage corporation of 14-bit with a variable sampling frequency of about 100MHz, 8 channels, and a signal-to-noise ratio of 63 dB which is installed on a desktop computer. The triggered and the returned signals can be observed and stored by Gage Scope (professional edition) Ver.310 software installed on the system . The sampling frequency is 100 Mega-Samples Per Second (MS/S). This signal represents sampling in the time domain with steps of 10 Nsec, which will provide a good separation feature for the desired test. The method of ultrasonic testing on the skin is reflective. The pulsating device stimulates the probe by sending a short pulse and generates a longitudinal ultrasonic wave. Since the probe is a supersonic transmitter and receiver, the returned waves are received by it and turning into an electrical signal. Then the return signal is received by the analog to digital converter and the digital data are stored on the computer.

Table 1. Device settings.

Parameter	Value
Damping	Position 7 = 100 Ω
Energy	Position 4 = 104 μJ
Depth	8000 MS
Sampling rate	100 MS/S

In order to compare the results obtained in this study, radiographic and ultrasonic images of test sample were used. Radiographic images are provided with the PARS PAD device of PMX-600 and ultrasonic images are provided by GE Voluson E10.

PULSE-ECHO TECHNIQUE

One of the most common types of ultrasonic tests is the reflection test. This test can be done either by contact or by immersion. The test is more reliable in immersion condition, because of the uniformity of thickness of the intermediate material and the absence of pressure on the probe placed on the body. But because of the much higher cost of equipment for immersion testing, as well as the impossibility of immersing most of the examined bodies in the water, the contact test is more appropriate in these circumstances. Therefore, in this research, ultrasonic testing is a reflective contact method and due to lack of access to appropriate equipment, only A-Scan method has been used. Signals are processed, after A-Scan and receiving signals. By processing the signal, the ultrasound sweep time is determined in the tissue. Among the methods for signal processing to accurately estimate the time interval between consecutive echoes, the correlation method is the most common and one of the oldest methods. In this method, from two consecutive echoes, the cross correlation function is obtained [25]. The correlation function between two signals is obtained by the Fourier transform of their frequency, and then its inverse Fourier transforms in the time domain [26]. The correlation function in the time domain has a maximum point, and the distance from this point to the midpoint of the correlation function is the same time interval between two consecutive echoes. The mathematical relations and the way to apply this method to calculate the interval between two signals are mentioned in numerous references. To determine the position of the defect under the skin, we calculate its distance to the skin surface. Therefore, we consider the distance between the defects to the skin surface as d. When the returned echo is received by a probe, the wave goes through the same path twice (the back and forth path), so we consider the distance between the defect to the skin surface as 2d. Time interval between the first and second echoes is Δt. Also the velocity (V) is defined by the division of distance to time:

$$v = \frac{2d}{\Delta t} \tag{1}$$

CALCULATING TIME USING SIGNAL PROCESSING

The selection of suitable analysis procedure and computation software more important. experimental procedures are the most suitable method for such subjects; But it's very expensive. Today's using numerical methods to simulate behavior of materials can reduce design and experiment cost. But second approach where the identification of material behavior is numerically and experimentally considered represents an appropriate method for attaining the desired result. The MATLAB software is an appropriate software to calculate waveform time. This application has been used in this study [27].

To do this, the desired echo is selected on the waveform, and by choosing the Data Cursor button, we click on the peak of the wave where the wave is suddenly deformed, then the software will show its X, Y Coordinates (see Figure 1), where the X-axis number corresponding to time of that point of the echo. By choosing two points of the echoes that enter the piece and the echo that returns after the collision to the defect and calculation the difference between them, the time between two echoes is obtained. Should be selected carefully to equal echoes.

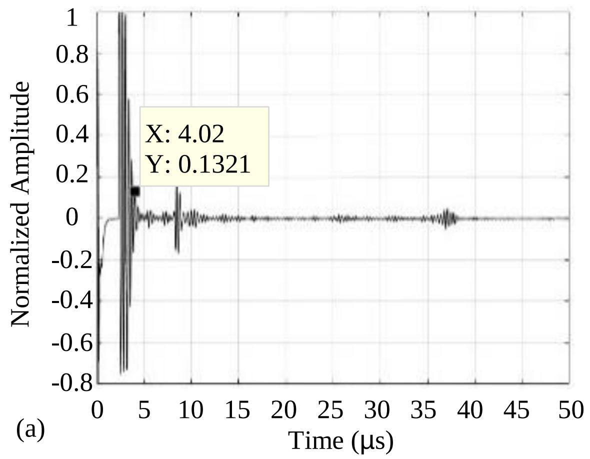

Figure 1. Selected points on the graph and calculation of time difference: (a) First echo and (b) Second echo

$\Delta t = 8.44 - 4.02 = 4.42$ µs

PURPOSE AND DESCRIPTION OF THE TEST

Laboratory Sample Preparation

As sound is a mechanical phenomenon, and ultrasonic waves cannot have propagated in vacuum, therefore; for better transmission of waves into the skin, was used the razor to shave hair and wool on the skin, which causes air detention (see Figure 2(c)), and also used water as an intermediate material for better coupling of the probe with the skin.

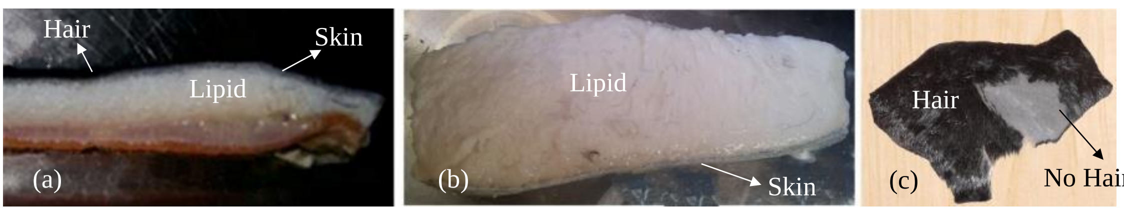

Figure 2. Sample test, (a) Cow skin, (b) Sheepskin with fat and (c) Cow skin without hair

To understand the effect of thickness on ultrasonic waves, used sheepskin with lipoma (under skin fat) of its tail fat, which was prepared in form of stairs with different thicknesses to compare the return time of transmitted ultrasonic in different thicknesses (see Figure 3).

Figure 3. Sheep’s tail fat which cuts in form of stairs

Also, to investigate the sound behavior in dealing with a defect, a cow's skin sample with a defect on it and needles, metal parts, or syringes are used to inject water or other fluid into tissues to create an artificial condition (see Figure 4).

Figure 4. Examples of skin defects: (a) artificial defects created with a surgical blade in cow skin, (b) artificial defects created with a needle in sheepskin, (c) Warts, a natural defect

Select the Appropriate Sampling Tool

Two samples of 3.5 and 10 MHz probe and one part of the cow's skin selected, then considered a spot on the skin and marked it. Then, by using a 3.5 MHz probe, was done sampling by sending and receiving sound waves in the tissue, after Sampling and simulation by MATLAB software, the following graph (Figure 5) was obtained.

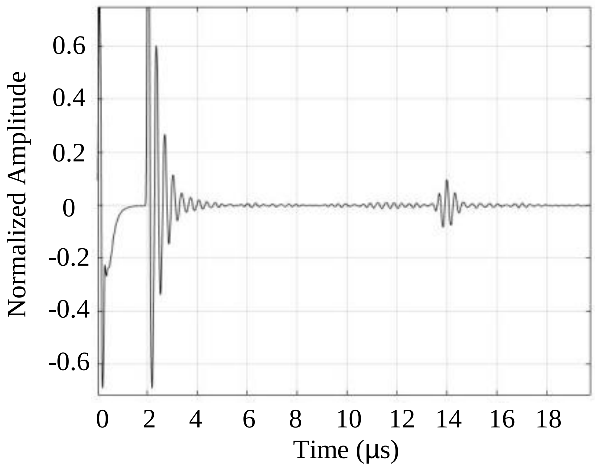

Figure 5. Obtained graph from cow’s skin by 3.5 MHz probe

As it can be seen in the Figure 5, there is a reflective echo that occurs when the wave goes out of the skin because of the difference in sound impedance outside and inside of the skin. Then we replace the probe and use the 10 MHz probe instead of the 3.5 MHz probe and again, was sampled the same spot already was done by 3.5 MHz probe. After simulation, we obtained the following graph (Figure 6) using the MATLAB software.

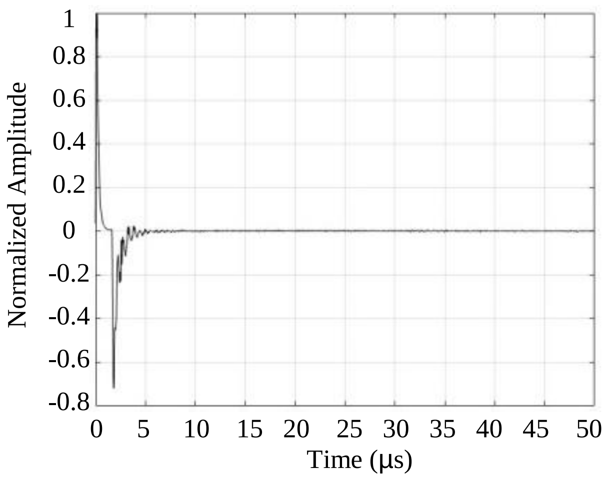

Figure 6. Obtained graph from cow's skin by 10 MHz probe

As it can be seen in the Figure 6, there is no reflective echo, and the wave is depreciated as it enters in and is seen as a line and has no reflection (although if it is magnified, it has a sinusoidal shape). By comparing the two diagrams and Eq. (2) and waveforms obtained above, as well as comparing the probes by Jitendrakumar et al, it is found that increasing the frequency reduces the penetration depth and increases the resolution (see Table 2). Since it is necessary to identify a subcutaneous defect with a short distance from the surface of the skin, it is not appropriate to use a high frequency probe. So the 3.5 MHz probe is better for testing.

$$\lambda = \frac{v_{(m/s)}}{f_{(Hz)}} \tag{2}$$

In this equation, λ is the wavelength, v is the sound speed, and f is the frequency. This equation shows that the frequency (f) is inversely related to the wavelength (λ).

Table 2. Comparison of the resolution and penetration depth of the various probes [28]

Penetration depth mm	Resolution µm	Probe's frequenc MHz
50 - 70	210	7.5
35	158	10
12 - 15	88	18
8 - 10	72	22
4 - 6	48	33
4 - 4	31	50
2 - 3	21	75
0.8 – 1.5	16	100

According to Maggi et al. the fat density is $0.95\ gr/cm^3$, muscle density $1.04\ gr/cm^3$ and skin density is $1.20\ gr/cm^3$. Thus, it can be assumed that this fact leads to attenuation of high frequencies [29].

Diagnosis of Subcutaneous Defect

To understand how ultrasonic waves can help to detect a subcutaneous defect, at first a healthy skin was used and sampled by a 3.5 MHz probe. After the obtained simulation of the signals from the software, the following graph (Figure 7) was obtained.

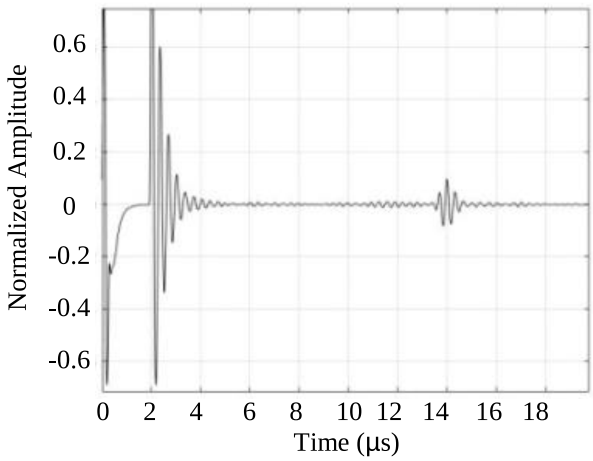

Figure 7. Obtained graph from cow's healthy skin by 3.5 MHz probe

There is only one reflective echo in this graph, which is related to the exit of the wave from the tissue. Again created an artificial defect in the subcutaneous tissue by a surgical blade (Figure 8(a)), at the point where previously was sampled and placed the probe. Therefore, by immersing the surgical blade into the tissue, an artificial defect is caused, Sampling was done again. After sampling the following graph and simulation (Figure 8(b) and (c)) was obtained.

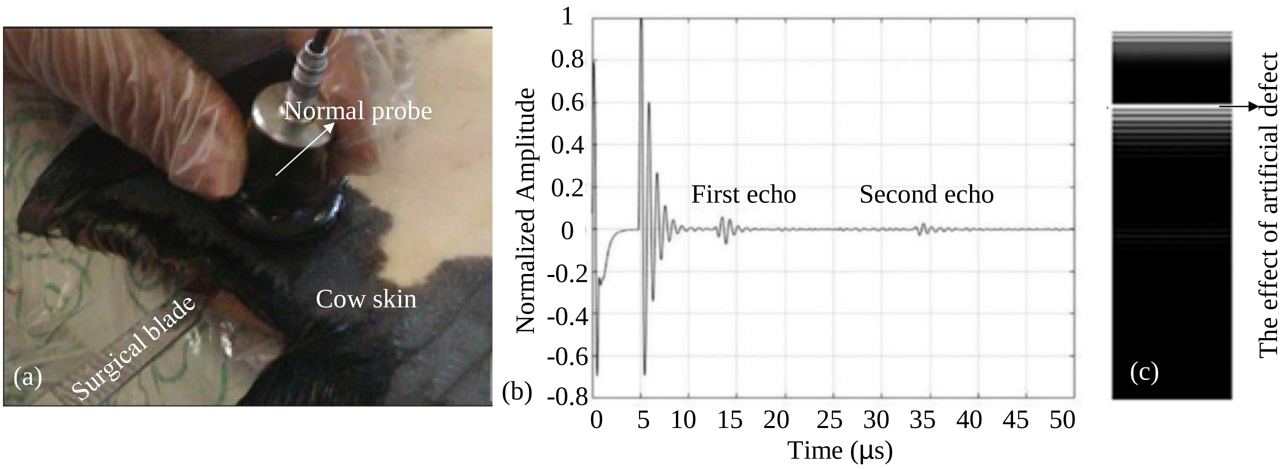

Figure 8. Obtained graph from the cow skin with a surgical blade in it by 3.5 MHz probe: (a) Test step, (b) graph obtained in MATLAB program and (c) simulated image in MATLAB

As shown in the diagram in Figure 8(b), there are two reflective echoes. The first echo is related to the collision with the surgical blade and the second echo refers to the exit of the wave from the tissue. Therefore, due to the difference in time between two echoes, they are fully recognizable and can be easily detected by the interpretation of the waveform. In order to compare and ensure that the echo is related to the defect, the skin and the defect made in it photographed by radiology and Ultrasonic device, and these photos also confirm the existence of a defect under the skin (see Figure 9 and Figure 10).

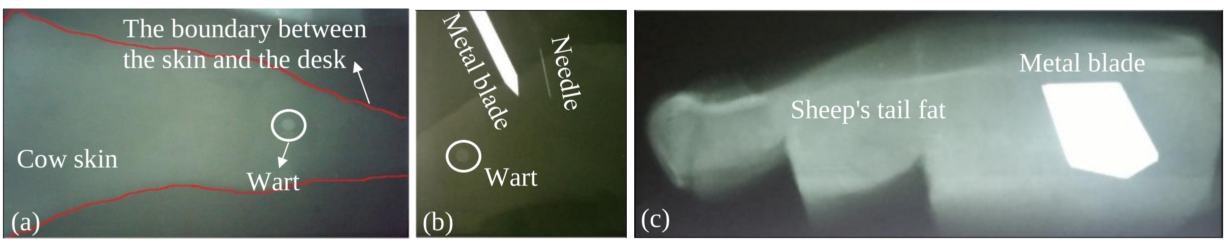

Figure 9. Display of subcutaneous defects in radiological images: (a) Wart display, (b) Wart and needle display and (c) Metal blade display

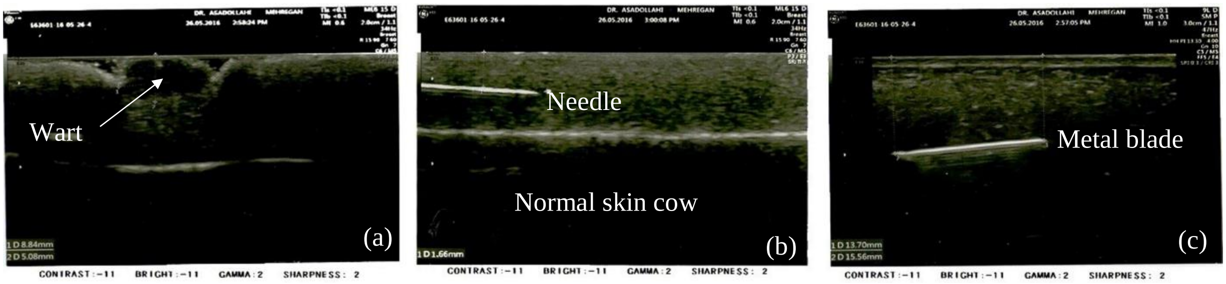

Figure 10. Display of subcutaneous defects in the ultrasonic images: (a) Wart display, (b) Needle display and (c) Metal blade display

Determine the Defect Distance to the Surface of the Skin

To determine the distance of the defect to the surface of the skin, the time interval between the two echo reflections is calculated (Echo received at the moment of the wave inflow into the tissue and echo reflection in the collision with the surgical blade) and then, by using the velocity of sound in that tissue through the Table 3, and Eq. (1), the distance between the defect and the skin surface can be calculated. In Figure 11, by selecting two echoes and clicking on them, the coordinates of that point of the echo will be specified. As shown in the diagrams in the figures, the axis x is the time axis and it's in μs, which is specified by calculating the difference between these two points of the ultrasonic wave. Then by using that data the distance can be determined.

Table 3. The speed of sound and density in the tissue and materials Related to ultrasonic [30]

Velocity mm/μs	Velocity m/s	Density Kg/m^3	Material
0.33	330	1.2	Air
0.6	600	300	Lung
1.45	1450	924	Fat
1.48	1480	1000	Water
1.54	1540	1050	Soft tissue
1.57	1565	1041	Kidney
1.56	1560	1058	Blood
1.55	1555	1061	Liver
1.6	1600	1068	Muscle
4.08	4080	1912	Scull
4	4000	7500	PZT

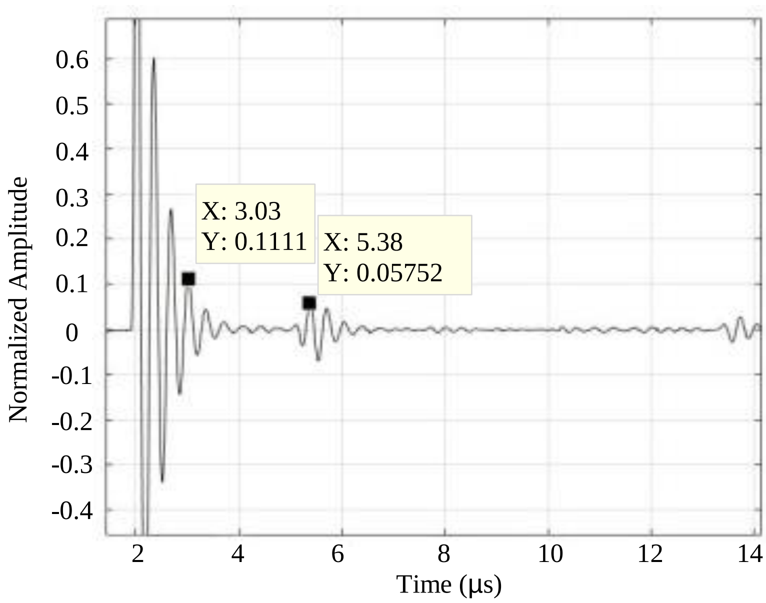

Figure 11. Selected and displayed coordinates of the selected echoes

$$V = \frac{2d}{\Delta t} \quad (1) \quad \Rightarrow d = \frac{V_{(mm/\mu s)} * \Delta t_{(\mu s)}}{2} = \frac{1.54 * (5.38 - 3.03)}{2} = \frac{1.54 * 2.35_{(mm*\mu s/\mu s)}}{2} = \frac{3.619_{(mm)}}{2} = 1.8\ \text{mm}$$

The results were compared with Pirmoradi's research [31] and the measurements performed with an ultrasonic device, and the results were quite similar. In Pirmoradi's research, by calculating the time interval and sample thickness, the velocity of sound was estimated to be 1598 m/s, indicating that the considered velocity in accordance with Table 3 was a correct choice and the presented size by the ultrasonic device (see Figure 12) indicates the correctness of the calculation method performed in this research.

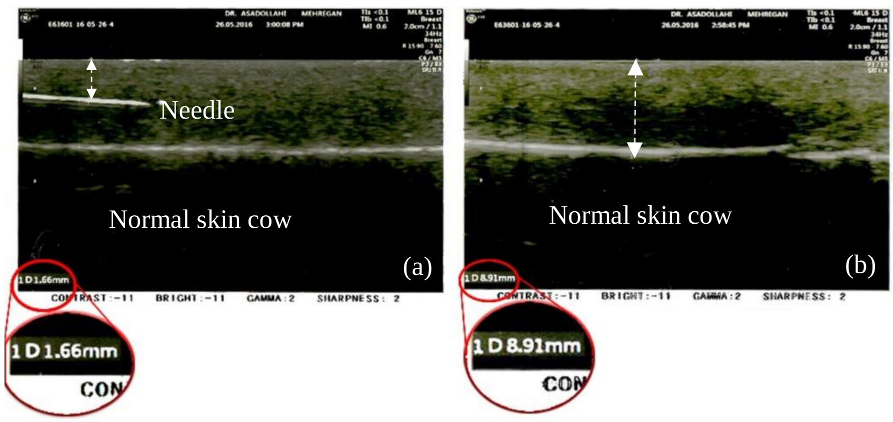

Figure 12. Measuring skin thickness: (a) Unhealthy and (b) Healthy with an ultrasonic device

Expansion Level of the Defect

One of the method to scan up is B-mode, in which with sweep it is possible to create a linear image unlike mode A (pointwise). Due to the shortage of laboratory equipment, it was not possible to create an image in B-Scan mode. Therefore, by creating a wide defect in the tissue and identifying specific points on the surface of the skin, it can be sampled. Then with placing the information obtained in the sampling, respectively, marked points, B-Scan mode is simulated. But in ultrasonic devices, due to the use of phased array probes, there is a scan of the tissue without moving the probe (see Figure 13).

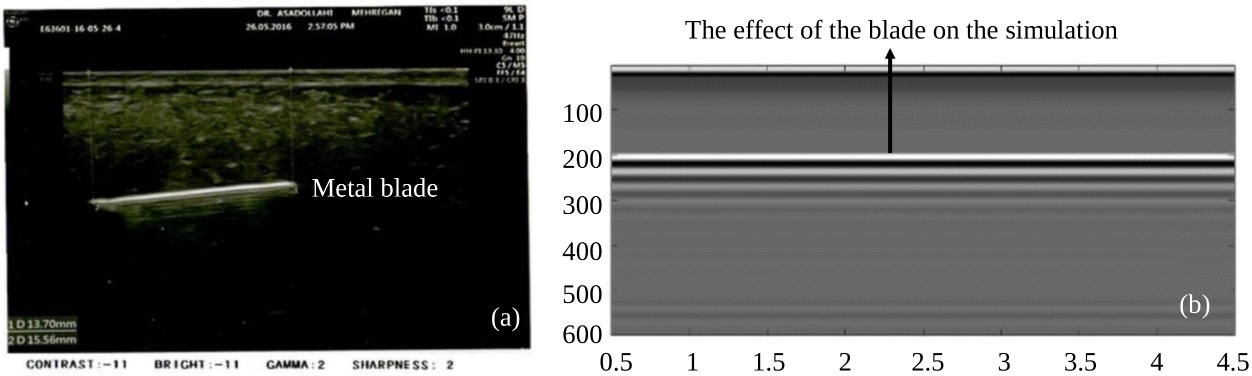

Figure 13. Display of the defect level: (a) In ultrasonic and (b) Combining received signals in A-Scan mode

Penetration Depth of the Defect

Due to the fact that the defect is made deep in the subcutaneous and its exact information such as dimensions, volume, stiffness, density and etc. is not available, so the Ultrasonic Critical- angle Reflectometry (UCR) device can be used to determine the velocity of the sound. The UCR is a special method for measuring the critical angle of failure, and thus it is possible to compute the sound velocity using these angles and the Snell's law. Note that UCR measures the speed at any point in the sample without the requirement of direct contact, and therefore it is a non-destructive method to measure not only the speed but also its distribution and alteration over a sample. In this method, the amplitude of the reflection wave is analyzed so there is no need for access and having two levels of the piece. Given that, in this method, only an angle measurement is required, so there is no need to measure the length of the path. By using this device shear and pressure wave's speed can be calculated [29].

With the longitudinal ultrasonic wave speed and using the method described in the previous step, the difference between the time that waves enter in and withdrawal from the defect can be determined and eventually determine the thickness of the defect.

Determine the Stiffness of the Defect

Tissue stiffness testing is one of the most important diagnostic methods. This method was initially invasive, but today several attempts have been made to obtain non-invasive methods under the name of Elastography. The base data used in the Elastography is the relative displacement of the tissue, which can be observed by ultrasonic [32]. Ultrasonic Elastography Technique is a new imaging technique with the ability of detection small amounts of mechanical properties, such as the elasticity of biological tissues. This technique was proposed by Ophir and his colleagues in 1991 with the goal of determining benign and malignant defects of the breast tissue without the requirement of surgical biopsy. Like the touch technique, it is based on this principle that the stiffness of the tissue can indicate the presence of the tumor in it. The first application of Ultrasonic Elastography was elastograms of the breast and muscle tissues that were in their natural environment in the body, which was obtained by Cespeds and his colleagues in 1993. In 1994, Gara and his colleagues examined the efficiency of this technique in the diagnosis of breast tumors. The results of this study showed that soft tissues such as adipose tissue appear as bright regions and harder tissues such as benign tumors and breast cancer tumors appear as darker regions in elastograms.

The tissue stiffness parameter is a function of the elastic coefficient and its geometric shape. Estimation of tissue properties such as Poisson's ratio, Young's modulus, is used to measure soft tissue stiffness. Young's modulus is defined as the ratio between transformation and monotonous compression. It should be noted that dynamic elastography is different from ultrasonic sonography. A shear wave and a longitudinal wave are used respectively in elastography, and ultrasonic [33].

$$E = \frac{\sigma}{\in} \tag{3}$$

In this equation, E is the Young's modulus, σ is the stress, and ε is the strain, or length changes relative to initial length. Young's modulus describes the stiffness of the tissue. By increasing the stiffness of the tissue, the Young's modulus also increases [34]. As regards, the healthy and unhealthy tissue density is considered almost the same, their elasticity coefficient is different. The Young's modulus for the three types of tissues and different conditions are reported in the Table 4 [32].

Table 4. Young's modulus in different tissues

	Types of Soft Tissue	Young's modulus KPa (E)	Density kg/ m^3
Breast	Fat in normal amount	18 - 24	1000 ± 8% (water density)
	With tubers	28 – 66	
	Fibrous	96 – 244	
	Carcinoma (malignant cancer)	22 – 560	
prostate	Normal anterior defect	55 – 63	
	Normal posterior defect	62 – 71	
	Benign Prostatic Hyperplasia (BPH)	36 – 41	
	Carcinoma (malignant cancer)	96 – 241	
Liver	Normal	0.4 – 7	
	Cirrhosis	15 – 100	

Shear waves (transverse waves) speed are less than pressure waves (longitudinal waves) and is published by the producing a tangential surface force between the layers of tissue. These waves travel in tissue at a rate of about 1 to 10 m/ s. The increase of Young's modulus, it increases the transverse wave propagation speed. The relationship between shear wave propagation speed and elasticity coefficient is determined as bellow.

$$E = \rho c^2 \tag{4}$$

In this equation, E is the Young's modulus (KPa), ρ is density (Kg/m^3) and C is transverse wave ($^m/_s$) propagation speed. Generally, tissue density cannot be determined inside the body, because the most volume of the tissue is composed of water, the density can be considered to be 1000 Kg/m^3. Given that in some sources, the fat density is 0.95 gr/cm^3, muscle density 1.04 gr/cm^3 and skin density is 1.20 gr/cm^3 [35]. This assumption is logical and for all tissues of the body, whether it's healthy or damaged, the density is about the same [32].

The tissue density is in Kg/m^3, Considering the density of tissue is considered to be (1000 Kg/m^3), with measurements of the propagation speed the elastic coefficient (Young's modulus) and, in particular, the stiffness of the tissue can be determined. As a result, the problem of determining the stiffness of the tissue changes into the problem of measuring the speed of the shear wave in the tissue. For this purpose, different solutions have been proposed under the name of elastography. Due to the obtained speed by the UCR device indicated in the previous step and the density, Young's coefficient can be obtained by Eq. (4) or (5).

$$E = \frac{\rho C_t^2 [3(C_l/C_t)^2 - 4]}{(C_l/C_t)^2 - 1} \tag{5}$$

In the equation E and C_t, C_l, ρ, respectively, are Young's modulus (KPa) and the transversal ultrasonic wave speed ($^m/_s$), the longitudinal ultrasonic wave speed ($^m/_s$), and the density (Kg/m^3). In this study, this test was not performed, Because of the shortage of laboratory equipment to create a shear wave and analyze it.

CONCLUSION

This study was about the use of ultrasonic waves because it is economical and offers a higher level of safety than other methods. The results of the ultrasonic examination were compared with the radiological data obtained. The results of this study proved that this method could be a proper and inexpensive approach to detect subcutaneous defects such as cancer tissues that required the observation of particular safety protocols. the results of this research are as follow:

Using the 3.5-MHz probe, the defect was detected at a distance of 1.8 mm, indicating a high level of reliability compared to the sonography imaging device. This was while the 10-MHz probe failed to detect the defect just near the skin surface. This test showed that the penetration depth decreased with increasing the frequency, although the resolution and clarity of the acquired images improved, confirming the findings reported by Jitendrakumar et al.

In the test, no reflection was observed in absence of any intermediate medium between the skin and the probe. Upon providing the intermediate, however, the apparatus began to record the reflections of the ultrasonic waves that were transmitted into the skin. This part of the test highlighted the fact that the sonic waves, in general, need some medium to propagate. In the absence of the intermediate medium, there was an air gap between the probe and the skin surface, and the large spacing among the air molecules made it difficult for the sound energy to spread. However, when the energy was set to transfer through a liquid (used water in the tests), the higher compactness of the molecules in the liquid let the ultrasonic wave penetrate the skin. By keeping the frequency constant in the experiments, the wavelengths recorded by the test apparatus showed that the ultrasonic wave travels at different velocities through different environments. This has been previously confirmed by the findings reported by Bushberg et al. In this test, we found that the ultrasonic wave attenuation is intensified in more compact tissues due to the absorption of the sonic energy in the tissue and the resultant heat generation. That is, the acoustic impedance increases with the medium density.

In this work, scans were acquired in A-scan mode at different positions and the results were correlated to simulate the imaging in B-Scan mode. Using the phase-array probe in the sonography, however, multiple piezoelectric sensors were incorporated into a single probe, with each piezoelectric sensor stimulated by an independent electric pulse of a particular phase, and the probe was moved linearly while continuously acquiring data to come with images in B-Scan mode.

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