A Novel Approach to Change the Breech Presentation of Fetus through Ultrasound

Samreen Amir, Manzoor Hashmani, B.S. Chowdhry

Abstract*—Breech presentation is one of the reasons for infant mortality and neurological disorders. Many conventional methods are being used to address the problem with different success rates and side effects, like External Cephalic Version, Elective C-Section, Moxibustions, gravity manipulation, acupressure, homeopathy, slant board exercise, visualization etc. The most regular way to deliver a breech baby in developed countries like USA, Australia, and Great Britain is Caesarean section and similar to any major surgery, it engross risks that may increase the maternal mortality. To avoid such risks, one solution is to stimulate unborn baby's reflex action to make him/her change its position. This paper presents a hypothesis to stimulate the fetal movement using ultrasound beam. The radiation force exerted by the ultrasound beam generates an acoustic vibration and the resulting sound can be used as a stimulus to the baby. The critical part in this approach is the transducer design, in this paper a linear ultra-sonic transducer design is studied as a stimulus source. The results show that the platform developed for this study can be effectively used to simulate and select the optimum design of the transducer. Moreover, the field strength plots given in the paper can be used to select the optimum number of transducer element given the required pressure and the focal depth.

***Index Terms*—Breech presentation, Ultrasound transducer**

I. INTRODUCTION

The basic health facilities are not available to every Pakistani hence the position of maternal and neonatal health is also pitiable. Approximately 30,000 women die each year due to pregnancy related causes [1]. It is also found that about 500 maternal deaths occur per 100,000 live births each year in Pakistan [2]. WHO & UNICEF put the statistics around 340/100,000 live births but in actuality it may be greater because of under registration of deaths in the country and poor reporting of cause of death information. The major factors of maternal death are haemorrhage (34.6%), eclampsia (30%), sepsis (19.2%), anaesthetic complications (11.5%) and hepatic encephalopathy (3.8%) [2]. After several amendment for birth-weight, planned c-sections, placental pathology and chorio-amnionitis, a strong relationship stayed between the presence of breech presentation and neonatal mortality. Breech presentation in preterm delivery is an independent risk factor for neonatal mortality [3]. The babies delivered by elective caesarean section around term face up to four times the risk of breathing problems as compared with babies delivered naturally [4]. Children who are born normal but with assistance from vacuum or forceps have a 20 percent increased risk of asthma [5]. A reported death toll of prenatal and neonatal due to asphyxia (one of the upshot of being breech) is about 18% of the total mortalities of the subject, according to National MNCH Program Statistics [6]. The problem is more acute in third world countries but also exist in countries like USA, U.K, and Canada etc.

Moro reflex or alarm reaction is the response of mind and body to a sudden unexpected stimulus. In human beings, the reaction may include physical movement away from the stimulus. The Moro reflex is one of the infantile reflexes and is usually present in complete form by week 34 (third trimester) in unborn. It is believed to be the only unlearned fear in human newborns. Ear is the first organ to develop to its full size and become fully functional. Out of 100% of the sensory energy (bio electrical energy) which enters the brain, 80-90% is supplied by the ear. The auditory nerves connect the inner ear with all the muscles in the body. Medical ultrasound scanners use high-energy pulses to probe the human body. Human sensing of modulated or pulsed ultrasound applied to the middle ear has been studied [7][8] The radiation force resulting from the impact of such pulses on an object can vibrate the object, producing a localized high-intensity sound in the audible range [9]. Ultrasound imaging devices are used frequently by numerous investigators to monitor fetal response in various types of stimulations, including acoustic signals [10]. The possibility of hearing pulsed ultrasound by bone conduction based on the acoustic radiation force has been considered [11]. There have been some indications that ultrasound may generate audible sound in the uterus [10], which may not be significant [12]. Fetal stimulation by ultrasound has been reported in the literature [13]. The radiation force is given by following equation [14]

$$F = \frac{(1+R)W}{c} \qquad (1)$$

Where, W, c, and R are the total incident power on the object, speed of sound, and the power reflection coefficient of the object, respectively, (R = 0 corresponds to a perfectly absorbing object).

II. PROCESS FLOW PORTRAYAL

The random movement of fetus has been reported when ultrasound beam is focused on the inner ear. The hearing is achieved through the resulting vibrations of pulsed wave ultrasound (US) when they hit reach the incus, a bony part of the inner ear.

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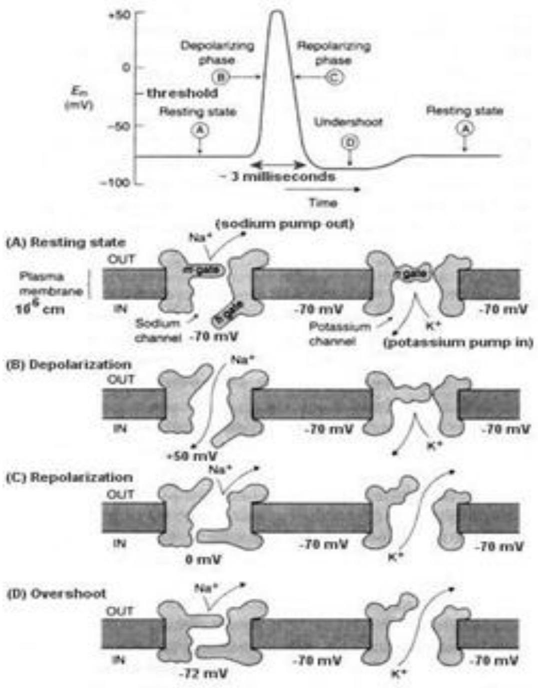

Figure 1: Action potential, Polarization and depolarization state [15]

The two important factors that influence this approach of stimulating an auditory evoked potential are the frequency and the strength of the resulting vibrations. If we investigate the mechanics of hearing then it indicates that hearing begins with pressure waves impacting the tympanic membrane, causing it to vibrate. The vibration is transmitted from malleus to incus and further on to stapes, causing the membrane of the oval window to produce pressure waves. Oval window can magnify the pressure 20 times and hence produce hearing. The pressure wave displaces the basilar membrane, transmitting pressure and displacing the membrane of the round window. Movement of the basilar membrane imparts a rocking action, proportional to degree of displacement, to the spiral organ which rests upon the membrane. Cilia dislodgment (unidirectional) let K+ channels to depolarize the hair cells, discharge of neurotransmitter and depolarization of dendrites increase the frequency of action potentials in the cochlear nerve. This electrical gradient actually allows potassium ions to flow into the counter charged hair cells during mechanical spur of the hair bundle. Since the hair cells possess a negative potential of -50 mV approximately and the electrical incline from endolymph to hair cell is at the value of 150 mV, which is the largest electrical potential found in the body [15].

The ear has remarkable capability to respond to different range of sound amplitude. The judgment of relative sounds is more or less logarithmic, such that a ten times boost in sound power is depicted as double loudness to the reference. The evident difference in loudness ranges between 3 dB at the threshold of hearing to an extraordinary 0.5 dB for loud sounds.

The RMS sound pressure of 20 µPa is considered as the threshold of hearing .This threshold is frequency dependent and it has been shown in figure 2 that the ear's sensitivity is best at frequencies between 1 kHz and 5 kHz [16].

To focus the US beam on the oval window controlled refraction or phase shifting in the transducer array can be

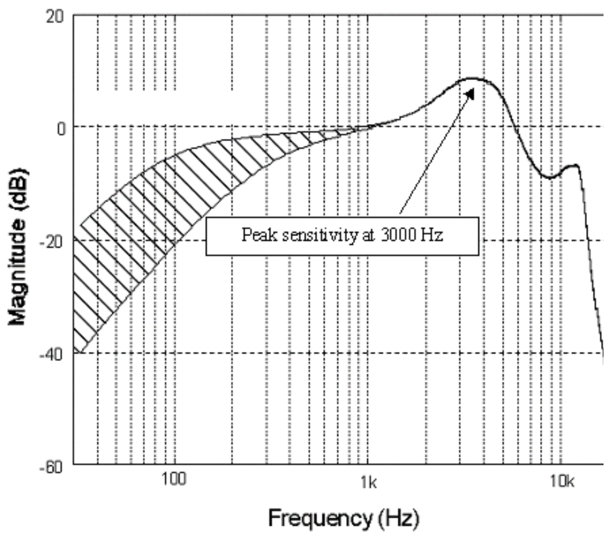

Figure 2: Sensitivity of the ear vs audible frequency range [16]

used. Refraction results due to different sound velocities in different tissue of the body. The amount of refraction is proportional to the velocity mismatch, the greater the mismatch, the greater the refraction [17]. Refraction at the skin interface can alter the transducer's focusing characteristics and its beam profile. The cumulative refraction induced errors degrade the image quality through distortion and loss of resolution in US imaging applications. But in this case we need to penetrate the US beam deep down to the oval window with enough pressure to cause the basiliar membrane vibrate, hence no reflections are required as in the case of imaging. This can be achieved with suitable transducer design and beam-forming at transmitter. The transducer in this case would only a transmitter not a transceiver. A separate imaging probe can be used to visualize the position of fetus. Since the imaging probe and the refracting beam would be operating on different frequencies as per their application requirement so they will not interfere.

The image resolution in medical imaging is directly proportional to the pulse frequency, the better the image resolution greater the transmission frequency. With higher frequencies, the attenuation of the sound beam by the medium is also greater and the beam cannot infiltrate much inside the body. Higher frequencies, for example 7.5 MHz are used to provide good detail of superficial organs such as the thyroid gland and the breast. Lower frequencies, for example 3.5 MHz are used for examinations of the abdomen [17].

The FDA ultrasound regulations permit an eight-fold raise in ultrasound intensity to be used in fetal ultrasound inspection. The key safety concern in prenatal diagnostic imaging is the temperature rise [17]. The efforts of investigators have concentrated on defining the temperature increases and exposure times which may give rise to biological effects and on determining the ultrasound levels which might, in turn, lead to those temperature rises. Keeping all the health and safety concern yet producing the desired results is the main objective.

The whole method depends on the initialisation of the hearing mechanism in the fetal inner ear. If we look in to the parameters required to generate that otoacoustic, are the depth to reach, pressure to meet the threshold requirements and the geometry of transducer to have all of it.

Figure 3 shows the block diagram for focusing an US beam, for focusing an US beam many methods can be used, which may include, array of transducers (shown in Figure. 4) in which beam focusing and steering can be achieved by phase scanning. Once the location and the pressure to be achieved at the focus is known then the individual elements of the transducer array are fed with the required amplitude and phase of the input signal. To calculate these amplitudes and phases, the geometry of the array, the working frequency and the velocity of the US wave in the medium is required.

Since in our method we do not intend to image anything so we are only interested in the design of a transmitter. Focusing can be achieved by curving the transducer itself or by using a lens in front of the transducer surface or by electronically introducing a phase delay to the transducer elements in an array. As in the geometric focal plane, far-field relation holds, the beam pattern is equal to the Fourier transform of the transducer aperture function. Hence, the pressure and the beam pattern can be calculated by knowing the transducer aperture function.

There are several parameters which have to be taken into consideration for the selection of the method to be employed to stimulate the fetal movement using ultrasound beam. These include the acoustic pressure to be achieved, diagnostic level or HIFU level and ultrasound frequency. The selection of frequency depends on the depth of the focus in the body. Moreover, the aperture size, transducer size which can be maximum of 3x5 cm2, else it becomes very expensive. Furthermore, to obtain a better focus within the body range, the aperture size should not exceed 1.15 wave lengths, for example, if the transducer is 5mm in length, it should have 50mm/1.54mm, about 3 elements. To finalize the transducer design, it is important that the proposed design is simulated and all its parameters are thoroughly studied. Accurate modeling requires correct entries and proper interpretation of the outputs. Experience is still the number one requirement in transducer design activity, but the proper tools for simulation provide great assistance.

The transducer given in Figure 5 is the one which we can consider for our application with few changes in number of elements if required. The point z may be taken as the point of the inner ear where the oval window is present and we need to find out the pressure at this point. Design is analyzed and tested through simulations with software tool like Ultrasim (MATLAB). Position for the placement of transducer to target the oval window can be determined on the basis of actual patients' data taken from authorized sonologist. Neural path way to enter the Central Nervous System can then be determined and response of bio-electrical signal through the neural pathway must be analyzed and stimulated to achieve total pattern response.

III. SIMULATION PARAMETERS AND PLATFORM

Focal number (F-number, F#) is the ratio of the focal depth (F) to the aperture width (a),

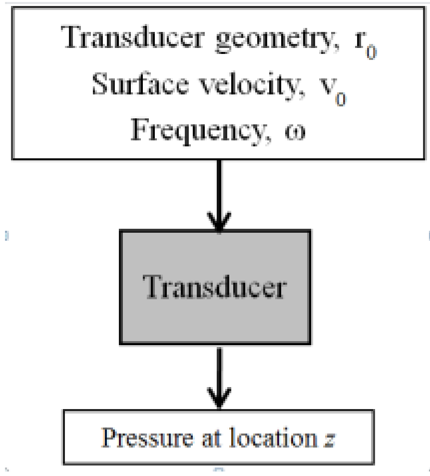

Figure 3: Block diagram of the US beam focusing.

Figure 4: Ultrasonic transducer arrays available in market.

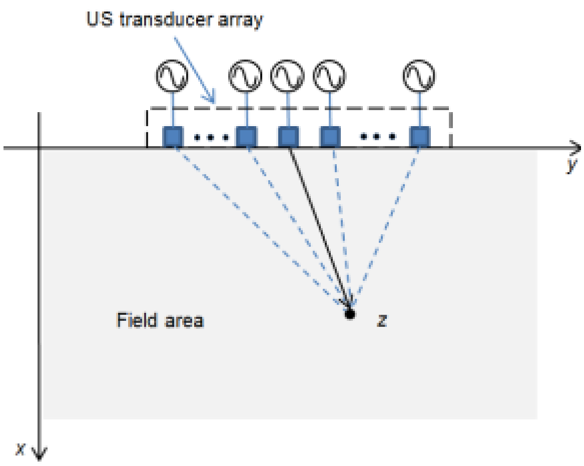

Figure 5: Simulated ultrasonic transducer arrays layout.

$$F\# = \frac{F}{a} \qquad (2)$$

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It determines the minimum lateral resolution (beam width) hence lower the F-numbers more narrow the beam width. It also determines the depth of focus so that lower F-numbers give lower depth of focus. The focal gain, lateral resolution and the focal depth are all dependent on the F-number. However, high pressures, narrow beam width and long focal depths becomes a trade-off, one cannot have it all. Also, in some applications the F-number that can be achieved is limited. In theory focusing all the way down to 8 cm can be achieved with F# = 2.

For simulation purpose the field area is in the xy-plane and the transducer array is placed along the y-axis (x=0 plane) and its center is aligned with the center of the field area. The x-axis is perpendicular to the transducer array. Once the focus point is defined the program calculates the relative phase differences on each transducer element and the signal is fed to the elements accordingly. The excitations from the transducer elements in the field area is propagated in the field region, by solving the wave equation numerically. The software also has the option in which the number of transducer elements can be varied, and it also calculates the maximum pressure at the focus point.

IV. SIMULATION RESULTS

In the simulations using the above defined parameters the number of transducer elements is varied between 3 and 14. Numbers of points in the total distance are taken as 100 that is the axial and lateral resolution. The sound velocity is taken as 1540m/s. The length and width of simulation step is set to 8e-3 units. The pulse frequency is 2MHz. The typical rate of absorption of ultrasonic energy is 0.5 dB/cm/MHz. Different plots are generated to give the pressure versus the number of elements. The focus point in the routine is changed to different values on x-axis from 30 units to 70 units with fixed y-axis at 50 units.

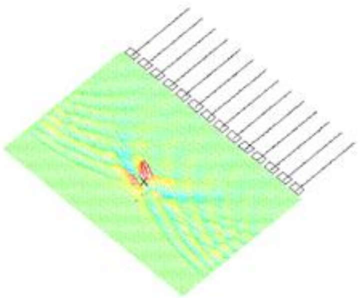

Figure 6: Field plots showing the transducer elements and focused beam at different positions.

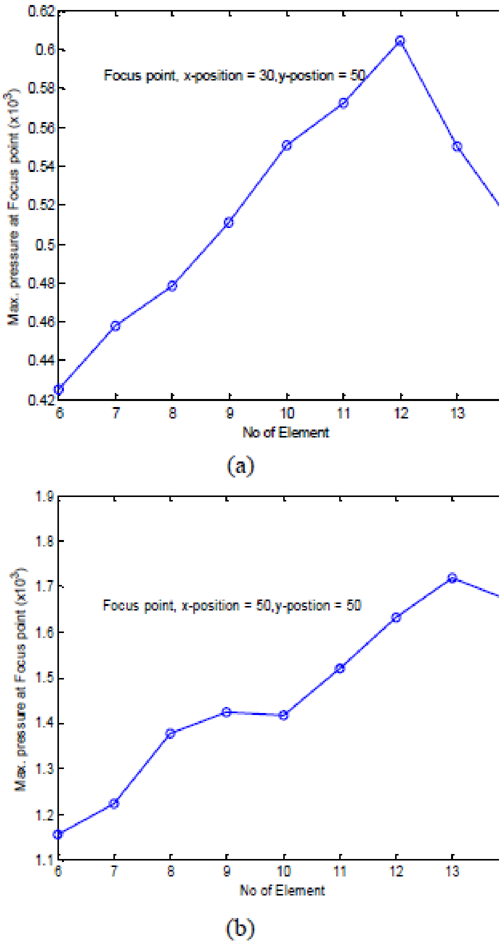

Figure 7(a)-(b): Plots of pressure versus the number of transducer elements.

The program also gives field plots at different simulations times, as shown in Figure 6. It generates a complete movie to show the propagation of energy from the transducers to the focus point. The interference patterns thus generated are also shown at different time instances. This visualization helps in understanding the field propagation and also the spill over energy in the side lobes.

The same platform is considered to compose the results for number of elements versus pressure on different focal dimensions. The program is used to find the maximum pressure versus the number of transducer elements at fixed focus point, as shown in Figure 7 & 8. It is observed (fig 7a) that when the axial depth is at 30 the maximum pressure is 0.42 mpa with 6 elements and it increases to 1.19 mpa for the axial depth at 40 and 50(fig 7c). The value of maximum pressure falls down to 0.65 mpa when the axial depth taken to 70 units(fig 7d) which is the maximum pressure value on the curve for the focal depth of (30, 50) with twice number of elements i-e 12. The depth versus pressure curves showed almost a fixed value of pressure which is 1.25 mpa at the depth of 12cm approximately for element numbers 5 and 3(fig 8b & c). Since the threshold pressure value is 20µpa for the movement of hair cell and stimulates hearing, which is very much possible to produce. But to be cautious about the safety of fetal hearing mechanism the pressure should not be very above the threshold baseline.

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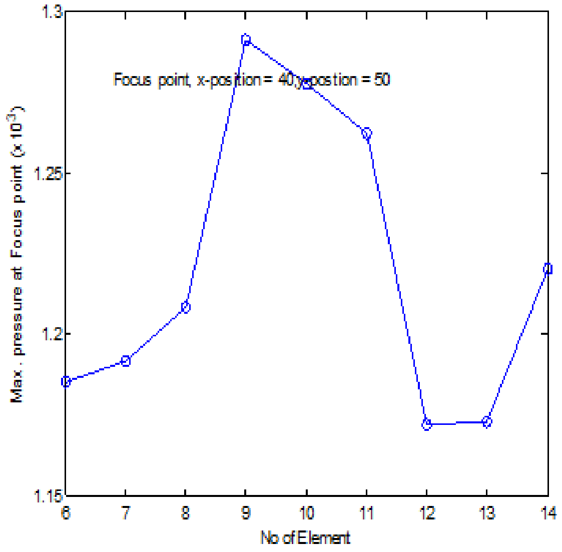
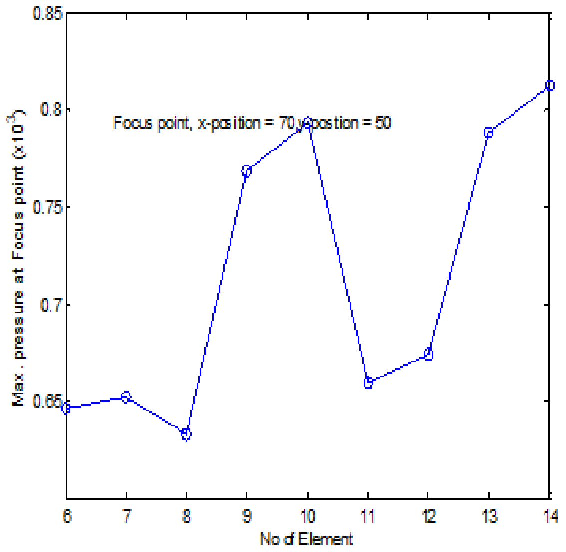
It is observed that with the increase in the number of elements the pressure at the focus point increases, therefore once the required pressure and the maximum limit of the transducers to radiate is known then the number of elements required in the transducer array can be determined from this data.



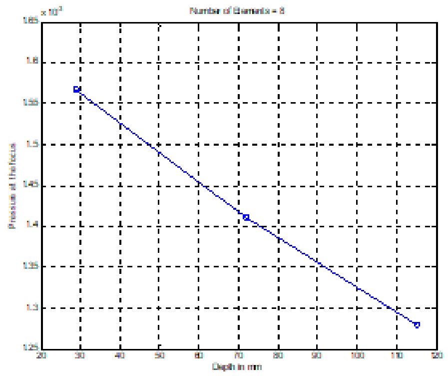
(c)



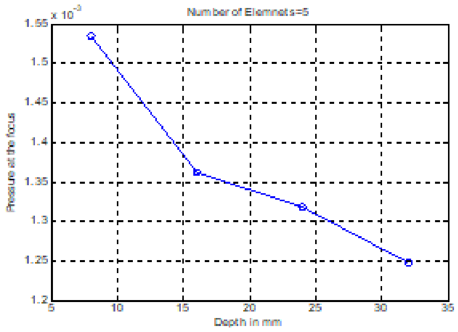
(d)

Figure 7 continue (c)-(d): Plots of pressure versus the number of transducer elements.

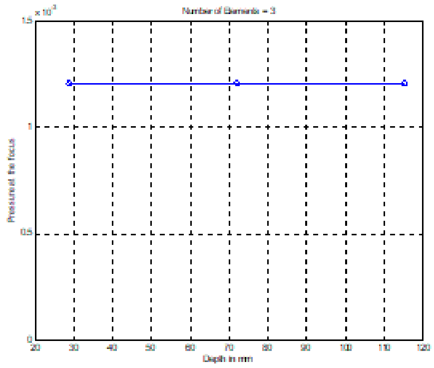
The simulations are performed to analyze the appropriate transducer design. Existing practical designs are simulated and the same platform is then used for further analysis to ensure the authenticity of the results. These simulations are performed to re-establish the tradeoff between pressure, number of elements and penetration depth.



(a)



(b)



(c)

Figure 8(a-c): Plots of pressure versus the depth of the focal point

V. CONCLUSION

There are several different ways to produce sound stimulus to reach the unborn baby's brain with much complex and big mechanical arrangements. It is shown that this can be easily achieved through an ultrasound probe, which is simple to use and readily available in almost every part of the world. A specially designed transducer can provide the pressure which may be focus on oval window through the US using the specially designed probe. In actual experiment on the fetus, to ensure about the effect of sound stimulus provided by the ultrasound beam, the auditory evoked potential can be measured through otoacoustic emission test or the brainstem evoked response audiometry. A separate Ultrasound transducer may be used for imaging with fetal movement monitor since the imaging frequency is different hence no interference shall be expected.

The results presented in this paper can be a guide to help in deciding the optimum number of transducer elements, giving the required pressure and the required beam size. The software platform can also be used to simulate different transducer designs.

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Dr.BS. Chowdhry From Thar to knowledge desert – Dr Chowdhry travelled all along with passion and enthusiasm. His list of achievements and awards is so long; simply he achieved Pride of Performance Award, Best Teacher Award, National IT Excellence Award, UNESCO/IAEA Guest Science Award, South Asia Star Award, and Presidential Izaz-e-Fazeelat highest academic distinction award. He has authored, co-authored and edited more than 20 books, and chaired several Technical Sessions in USA, UK, China, UAE, Italy, Sweden, Finland, Switzerland, Pakistan, Denmark and Belgium.