# Detecting Hip Dysplasia Using Acoustic Excitation in a Pig Model

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Timely detection of Developmental Dysplasia of the hip (DDH) in infants and children is crucial as DDH can lead to permanent hip instability if diagnosis is delayed [1]. Existing methods of DDH detection, such as ultrasound and x-rays, are expensive and require trained medical personnel to perform and interpret the tests. Furthermore, x-rays subject patients to ionizing radiation with its attendant cancer risks, especially problematic when repeat studies are performed. In the current study, an acoustic non-invasive approach for DDH detection in a postmortem pig model is presented. We previously designed and tested a similar approach in different simplified benchtop models of the hip joint [2]. A compact system to assess sound transmission through joints was also tested [3] [4]. Moreover, physics-based computational studies were carried out to explain biomechanical factors determining the reduction of dislocated hips [5] [6] [7] .

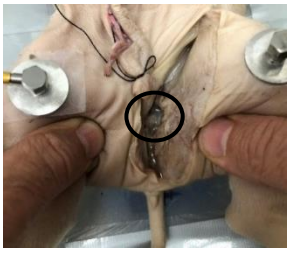


**Figure 1.**The set up showing the sensor location on left and right knees

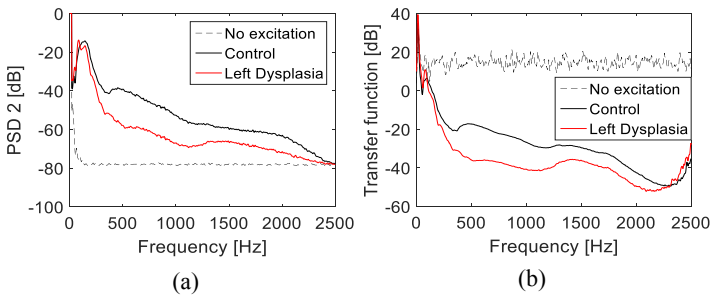
The experimental set up is shown in Figure 1. The postmortem animal was stimulated with band-limited white electrical noise (5-2500 Hz) at the sacrum while the transmitted sounds were measured at the left and right knees before and after hip dysplasia was surgically introduced in the left hip. The black circle in the figure marks the location of the displaced hip. The excitation signal generated by the computer was amplified using a digital amplifier that drove an electromagnetic exciter (iLouder, Model: QY40R-Z, Dongguan Qian Yin Electroacoustic Co., Ltd., China, weight: 199g; max diameter: 1.73 inch; power rating: 20W max). One uniaxial accelerometer (Model 3220A, Dytran Instruments Inc., Chatsworth, CA) with 10 mV/g sensitivity were used to detect the stimulus signal at the excitation point and two single-axis accelerometers (Model 352C65, PCB Piezotronics, Depew, NY) of 100 mV/g sensitivity were used to detect the transmitted signals at the two measurement points. A multi-channel charge amplifier was also used to amplify the accelerometer output. The power spectral density (at the left and right hip), and transfer function (between sacrum and left and right hips) were determined [8] [9] for the control and hip dysplasia cases. The power spectral density function (PSD) is an estimation of the strength of the vibrations (energy) as a function of frequency. Calculations of PSD were performed by Fast Fourier Transform (FFT). The following equation was used to determine the transfer function ($TF_{xy}$ *(f)*) between any two signals x, y:

$$TF_{xy}(f) = \frac{P_{xy}(f)}{P_{xx}(f)} \quad (1)$$

Here, $P_{xy}$ is the cross-power spectrum between the two signals, and $P_{xx}$ is the power spectrum of the first signal. The power spectral density ratio (PSDR) between the high frequency band (300 to 1200 Hz) and the low frequency band (5 to 300 Hz) was also calculated. The power spectral density (PSD) and the transfer function for the left hip (affected side) are shown in Figure 2(a) and 2(b), respectively, for the control and dysplasia cases.

Figure 2(a) shows that the power spectral density for low frequencies (F< 300 Hz) was comparable for the control and dysplasia cases. The PSDR was -20 dB and -35 dB in the control and hip dysplasia cases, respectively, with the greater sound attenuation indicative of decreased acoustic coupling and transmission in the dysplasia affected side. Similarly, the transfer function ratio between the high and low frequency

bands decreased from -24 dB in the control state to -37 dB in this dysplasia model as shown in Figure 2(b). For the unaffected side (right side), much smaller changes in PSD and transfer function ratios were seen.




(a) (b)

**Figure 2.** (a) The power spectral density (PSD) for the left hip (PSD 2); (b) Transfer function for the sacrum to left hip.

Results revealed that on the affected (i.e left) side, the power spectral density, and transfer function between the sacrum and knee were decreased with dysplasia. There was significant transmission drop (in the affected side) with dysplasia in this pig model for the high frequency band of 300 to 1200 Hz. A p-value of $< 0.02$ was achieved using t-test. This suggests that the presented approach may be beneficial for rapid, safe, non- invasive detection of DDH. Further research in humans is needed to investigate the utility of this method in newborn and neonates.

## ACKNOWLEDGMENTS

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## Introduction

- Developmental dysplasia of the hip (DDH) is a problem with the way a baby's hip joint forms before, during, or after birth which causes an unstable hip.
- In severe cases, the hip joint can dislocate or lead to trouble walking.

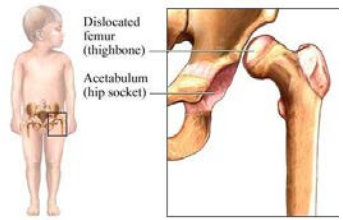



Figure 1: Developmental dysplasia of the hip

- Early detection of Developmental Dysplasia of the hip (DDH) in infants and children is crucial as DDH can lead to permanent hip instability if diagnosis is delayed.
- Existing methods of DDH detection, such as ultrasound and x-rays, are costly and require trained medical personnel to perform and interpret the tests.
- X-rays subject patients to ionizing radiation which is undesirable especially when repeat studies are performed.
- In the current study, an acoustic non-invasive approach for DDH detection in a postmortem pig model is presented.

## Methods: Pig Model

- One preserved pig (Carolina Biological Supply Company, Burlington, North Carolina) was used in this experiment.
- Surgery was performed where the ligaments holding the left hip joint were cut. This allows the left hip to be displaced at different levels.
- No surgery was performed to the right hip.
- Both femur heads are held in the acetabulum by hand (this will be called "control" case) to simulate the healthy state.
- The dysplasia state is simulated by actively pulling the left femur head out of the acetabulum (this state will be called "Left Dysplasia").
- This approach is meant to provide more control of the contact between the femur head and acetabulum.
- The pig was placed supine in a plastic container.
- The upper extremities were tied to the side of the container to help keep the pig supine.

## Methods: Hardware and Analysis

Figure 2: The set up showing the sensor location on left and right knees. The black circle in the figure marks the location of the displaced hip.

- The animal was stimulated with band-limited white electrical noise (5-2500 Hz) at the sacrum.
- The excitation signal generated by the computer was amplified using a digital amplifier that drove an electromagnetic exciter (iLouder, Model: QY40R-Z, Dongguan Qian Yin Electroacoustic Co., Ltd., China, weight: 199g; max diameter: 1.73 inch; power rating: 20W max).
- One uniaxial accelerometer (Model 3220A, Dytran Instruments Inc., Chatsworth, CA) with 10 mV/g sensitivity was used to detect the stimulus signal at the excitation point
- The transmitted sounds were measured at the left and right knees before and after hip dysplasia was introduced in the left hip by pulling the femur head.
- Two single-axis accelerometers (Model 352C65, PCB Piezotronics, Depew, NY) of 100 mV/g sensitivity were used to detect the transmitted signals at the two measurement points.
- Sensors (accelerometers) were secured over the left and right condyles, respectively, using double sided tape.
- A multi-channel charge amplifier was also used to amplify the accelerometer output.
- The power spectral density (at the left and right hip), and transfer function (between sacrum and left and right hips) were determined for the control and hip dysplasia cases.
- The power spectral density function (PSD) is an estimation of the strength of the vibrations (energy) as a function of frequency [1].
- PSD Calculations were performed by Fast Fourier Transform (FFT).
- The following equation was used to determine the transfer function ($TF_{xy}(f)$) between any two signals x, y [2] :

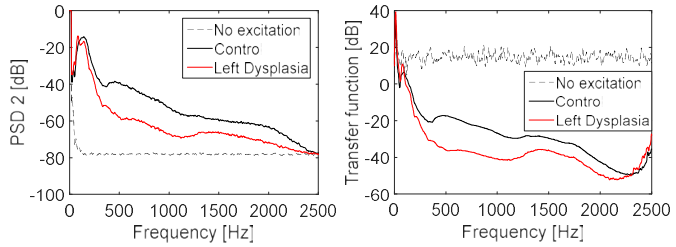
$$TF_{xy}(f)=\frac{P_{xy}(f)}{P_{xx}(f)}$$

where $P_{xy}$ is the cross-power spectrum between the two signals, and $P_{xx}$ is the power spectrum of the first signal.

- The power spectral density ratio (PSDR) between the high frequency band (300 to 1200 Hz) and the low frequency band (5 to 300 Hz) was also calculated.

## Results

- The power spectral density (PSD) and the transfer function for the left hip (affected side) are shown in Figure 3, for the control and dysplasia cases.




(a) (b)

Figure 3. (a) The power spectral density (PSD) for the left hip (PSD 2); (b) Transfer function for the sacrum to left hip.

- Figure 3 shows that the power spectral density for low frequencies (F< 300 Hz) was comparable for the control and dysplasia cases.
- The PSDR was -20 dB and -35 dB in the control and hip dysplasia cases, respectively, with the greater sound attenuation (i.e., -35 dB) indicative of decreased acoustic coupling and transmission in the dysplasia affected side.
- Similarly, the transfer function ratio between the high and low frequency bands decreased from -24 dB in the control state to -37 dB in this dysplasia model as shown in Figure 3(b).
- For the unaffected side (right side), much smaller changes in PSD and transfer function ratios were seen (not shown in the Figure).

## Summary

- The objective of this study is to detect hip dysplasia using a pig model.
- Results revealed that on the dysplasia affected (i.e left) side, the power spectral density, and transfer function between the sacrum and knee were decreased with dysplasia.
- There was significant transmission drop (in the affected side) with dysplasia in this pig model for the high frequency band of 300 to 1200 Hz.
- A p-value of < 0.02 was achieved using t-test.
- This suggests that the presented approach may be beneficial for rapid, safe, non-invasive detection of DDH.
- Further research in humans is needed to investigate the utility of this method in newborn and neonates.

## Acknowledgement

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