A Chicken Model for Acoustic Detection of Developmental Hip Dysplasia

P. Raodeo[1] L. Brown[1], M. Hartig[1], T. Hassan[2], R.H. Sandler[2,3], C. Price[3,4] and H.A. Mansy[2]

1. Burnett School of Biomedical Sciences, University of Central Florida, Orlando, Florida, USA
2. Dept. of Mechanical and Aerospace Eng., University of Central Florida, Orlando, Florida, USA
3. College of Medicine, University of Central Florida, Orlando, Florida, USA
4. International Hip Dysplasia Institute, Orlando, Florida, USA

{pinak.raodeo, 128lcb, mayahartig, thassan}@knights.ucf.edu, rhsandler@gmail.com, charles.price@orlandohealth.com, hansen.mansy@ucf.edu

Developmental dysplasia of the hip (DDH) is the instability of the hip joint, which occurs in 36 to 64 per 1000 births in the United States. Approximately one in five hundred infants are born with a dislocated hip where the femoral head lies outside the acetabulum [1]. If not detected and treated before six months of age, dislocation can lead to abnormal gait, limb length differences, issues in posture, chronic pain, and joint stress. If DDH goes unrecognized, patients often require invasive procedures such as open reduction or hip reconstruction, which unfortunately do not have a high success rates [2]. Pediatricians often use the "Barlow and Ortolani maneuvers" to detect hip dysplasia in infants. These techniques are highly skill dependent and lack sensitivity with only 54% accuracy in detecting DDH and, therefore, developing new screening methods would be beneficial [1]. Imaging techniques such as ultrasound and radiography can be used to validate the results of the Barlow and Ortolani tests but may be expensive, while ionizing x-ray exposure can be dangerous to infants [3]. If proven to be adequately predictive, a non-invasive bedside technique based on audible sound transmission would be a possible option to detect DDH because it would be safe, comfortable, inexpensive, and easy to use. Previous studies used this approach to detect DDH on simplified benchtop and pig models, which suggested that acoustic detection could be used to indicate dislocation [4]-[7]. The current study focuses on applying a similar method for DDH detection in a chicken model. Because the chicken joint is similar to a baby joint, it is a possible model to initially demonstrate potential utility [8].

The experimental setup is shown in Figure 1. Dislocation of the chicken knee joint was induced gradually to simulate different degrees of DDH in 3 chicken quarters with an approximate weight of 360 g. The length of the chicken femurs and tibias were about 16 cm. The knee joint was used instead of the hip joint because of ease of access, less waste of resources, and storage capacity in the lab. In addition, the knee joint and hip joint are both synovial (i.e., have a higher degree of motion and similar anatomical features) [9]. A surgical scalpel was used to expose the femoral head and the articular surface of the tibia bone, where screws were drilled into the bones to affix the acoustic sensors. The specimen was stimulated by an exciter emitting band-limited white noise (10-2500 Hz) on the articular surface of the tibia. The sensors shown in Figure 1 measured the transmitted noise at both the articular surface of the tibia and the femur head during the intact state (control), partial dislocation, foam inserted in the site of dislocation, and complete dislocation. As seen in Figure 2, foam (density~0.1g/ml) was inserted into the partially separated joint to create an intermediate state between intact and complete dislocation since the foam density is between air (density~0.001g/ml) and soft tissue (density ~ 1 g/ml).

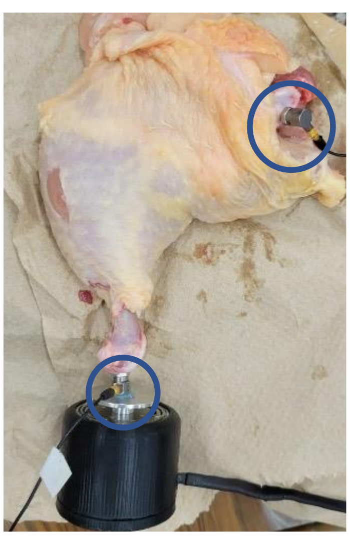
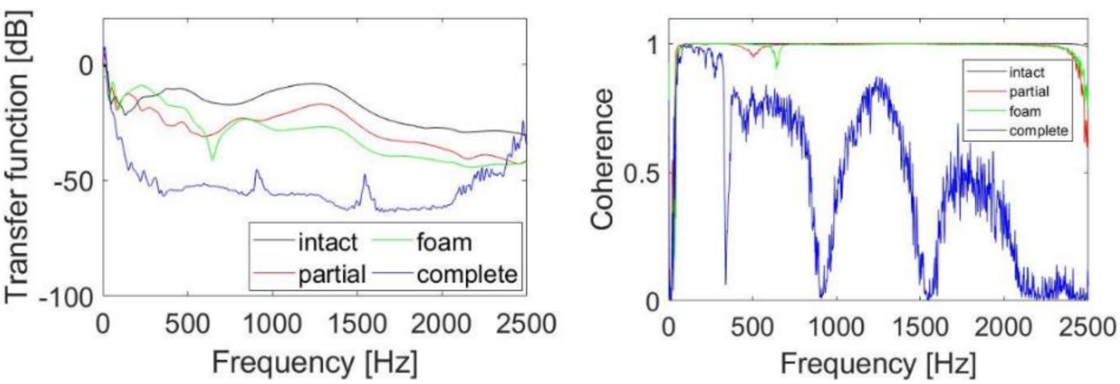


Figure 1. The completely intact knee joint setup. One sensor was positioned at the femoral head, and the other at the distal end of the tibia.

Each state of dislocation was repeated three times to confirm repeatability. The degrees of dislocation were induced in the same chicken leg on the same day to avoid day-to-day variation. The transfer function and

(a) (b) (c)

Figure 2. (a) Partially dislocated knee joint; (b) Foam inserted in knee joint; (c) Completely dislocated knee joint



(a) (b)

Figure 3. (a) Transfer function between the stimulus and transmitted signals; (b) Coherence between the stimulus and transmitted signals

coherence between the stimulus and transmitted signals were calculated, plotted, and compared across trials. Transfer function differences were also quantified. The data processing code was written using MATLAB.

Figure 3 shows a sample of the transfer function and coherence for the intact and different dislocation states. This data suggests that there is a decrease in the transfer function as the joint becomes more dislocated. A drop of about 50 dB in the transfer function was seen in complete dislocation compared to the intact state. The transfer function of partial dislocation cases was between the intact and completely dislocated states. There was a clear, frequency-dependent coherence loss with complete dislocation as well. These trends were most clear in the 500 Hz to 2000 Hz frequency band in all the specimens. The average drop in transfer function from the intact knee to partial dislocation was 6.268 dB in the 500-1100 Hz frequency range and 10.805 dB in the 1101-2000 Hz frequency range as seen in Figure 3. For the four samples studied, this drop between the intact and partial cases for our 4 samples was 8.300 ± 2.199 for the 500-1100 Hz range and 11.786 ± 3.645 for the 1101-2000 Hz range. This data suggests that the transfer and coherence may be utilized to provide an effective, non-invasive, and fast screening method to detect DDH in infants.

Although imaging methods such as ultrasound are also non-invasive, they are not commonly used to screen for DDH. The proposed method, if proven effective in future human studies, may be used to complement the current Barlow and Ortolani maneuvers when screening for DDH. Limitations of this pilot study include that sensors were directly applied to the exposed bone that can transmit sound better than soft tissue.

Because the current setup cannot be used on exposed bone in humans, future testing needs to be done on human models to account for the sensors being placed on soft tissues. In addition to screening for DDH, the proposed method may also be applicable to other joint dislocations and conditions such as osteoporosis. More investigation is warranted to further explore the utility of this technique in a clinical setting.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. FW-HTF-P 2026516. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] S. Yang, N. Zusman, E. Lieberman, and R. Y. Goldstein, "Developmental Dysplasia of the Hip," *Pediatrics,* vol. 143, no. 1, 2019. [Online]. *https://pediatrics.aappublications.org/content/143/1/e20181147/tab-article-info*.

[2] P. Kotlarsky, R. Haber, V. Bialik, and M. Eidelman, "Developmental dysplasia of the hip: What has changed in the last 20 years?" *World Journal of Orthopedics,* vol. 6, no. 11, pp. 886-901, 2015. [Online]. *https://www.wjgnet.com/2218-5836/full/v6/i11/886.htm*

[3] B. A. Shaw, and L. S. Segal, "Evaluation and Referral for Developmental Dysplasia of the Hip in Infants," *Pediatrics*, vol. 138, no. 6, 2016. [Online]. *https://pediatrics.aappublications.org/content/early/2016/11/17/peds.2016-3107/tab-article-info*.

[4] T. Hassan, L. Mckinney, R. Sandler, A. Kassab, C. Price, F. Moslehy, and H. Mansy, "An Acoustic Approach for Detection of Developmental Dysplasia of Hip," *2018 IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*, Philadelphia, PA, USA, 2018. *https://ieeexplore.ieee.org/document/8615627*

[5] T. Hassan, *Detection of DDH in Infants and Children Using Audible Acoustics*, M.S. dissertation, Dept. Mech. and Aerospace Eng., University of Central Florida, Orlando, Florida, USA, 2019. *https://stars.library.ucf.edu/etd/6750/*

[6] T. Hassan, L. Mckinney, R. Sandler, A. Kassab, C. Price, F. Moslehy and H. Mansy, "A System for Measuring Sound Transmission Through Joints," *2019 IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*, Philadelphia, PA, USA, 2019. *https://ieeexplore.ieee.org/document/9037844*

[7] T. Hassan, R. Sandler, C. Price, A. Kassab and H. Mansy, "Detecting Hip Dysplasia Using Acoustic Excitation in a Pig Model," *2020 IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*, Philadelphia, PA, USA, 2020, pp. 1-3. *https://ieeexplore.ieee.org/document/9353621*

[8] M. Geswell, N. Sinha, M. Mandel, B. Wheatley, W. Mirenda, and M. Seeley, "Improving resident education through unstable chicken hips: a novel way to teach an infant hip examination," *Journal of Pediatric* Orthopedics, 2020. [Online]. *https://journals.lww.com/jpo-b/Abstract/2021/03000/Improving_resident_education_through_unstable.8.aspx/*

[9] T. M. Tamer, ""Hyaluronan and synovial joint: function, distribution and healing," *Interdisciplinary Toxicology*, vol. 6, no.3, pp. 111-125, 2013. [Online]. *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3967437/#CIT0090*.

A Chicken Model for Acoustic Detection of Developmental Hip Dysplasia

P. Raodeo[1], L. Brown[1], M. Hartig[1], T. Hassan[2], R.H. Sandler[2,3], C. Price[3,4], H. Mansy[2]

1. Burnett School of Biomedical Sciences, University of Central Florida, Orlando, Florida, USA
2. Dept. of Mechanical and Aerospace Eng., University of Central Florida, Orlando, Florida, USA
3. College of Medicine, University of Central Florida, Orlando, Florida, USA
4. International Hip Dysplasia Institute, Orlando, Florida, USA

Introduction

- Developmental Dysplasia of the Hip (DDH) refers to instability of the hip joint. DDH affects approximately 36-64 per 1000 births in the U.S.; about 1 in 500 infants are born with a completely dislocated hip joint.
- Early detection of DDH is important because it can lead to abnormal gait, limb length differences, issues in posture, chronic pain, and joint stress. as abnormal gait, limb length differences, issues in posture, chronic pain, and joint stress. Further, if DDH is not detected early, patients will need corrective procedures like open reduction or hip reconstruction, which often are unsuccessful.
- Currently, the "Ortolani" and "Barlow" maneuvers are used as screening processes for DDH in infants. However, these physical examination techniques have a sensitivity of only about 67% in experienced hands, and significantly less with non-expert examiners.
- Ultrasound and radiography could be used to validate DDH from the screening processes, but these tests are expensive and ionizing x-ray radiation poses a risk for infants.
- Previous studies have adopted audible sound transmission to detect DDH on simplified benchtop and fetal pig models, suggesting the utility of acoustic detection of DDH.
- The chicken joint has significant similarities to the baby hip joint in terms of structural and physiological anatomy, which makes it a possible model to test the proposed system.

Objectives

This study involves applying audible sound transmission to chicken knee joints to assess the utility of using the proposed acoustic method in the detection of DDH in infant hip joints. If this method proves to be accurate, it may provide an easy, inexpensive, noninvasive, and effective tool for DDH screening in infants.

Methodology

- Different degrees of DDH were induced in 4 chicken quarters with an approximate weight of 360 g. The length of the chicken tibias and femurs were about 16 cm long.
- The chicken knee joint was used instead of the chicken hip joint due to ease of access, less waste of resources, and available lab storage capacity.
- The articular surface of the tibia and the head of the femur were exposed using surgical tools, and screws were drilled into these regions as fixation points for the sensors. Two accelerometers were placed at the femoral head and the distal end of the tibia to measure transmission through the knee joint. The accelerometers were securely affixed to the screws as shown by Figures 1 and 3.
- An acoustic exciter emitted a band-limited white noise (10-2500 Hz) which stimulated the the distal end of the tibia.
- Four different states of the joint were tested: the intact state (control), partial dislocation, foam inserted in the site of dislocation, and complete dislocation.
    - The foam inserted at the site during dislocation had a density of approximately 0.1 g/ml. This was done to create an intermediate state between the intact knee and the completely dislocated knee since the foam had a density between that of air and soft tissue.
    - 9 trials (of the above states) were conducted for each chicken quarter. All trials were conducted on the same day to avoid day-to-day variation.

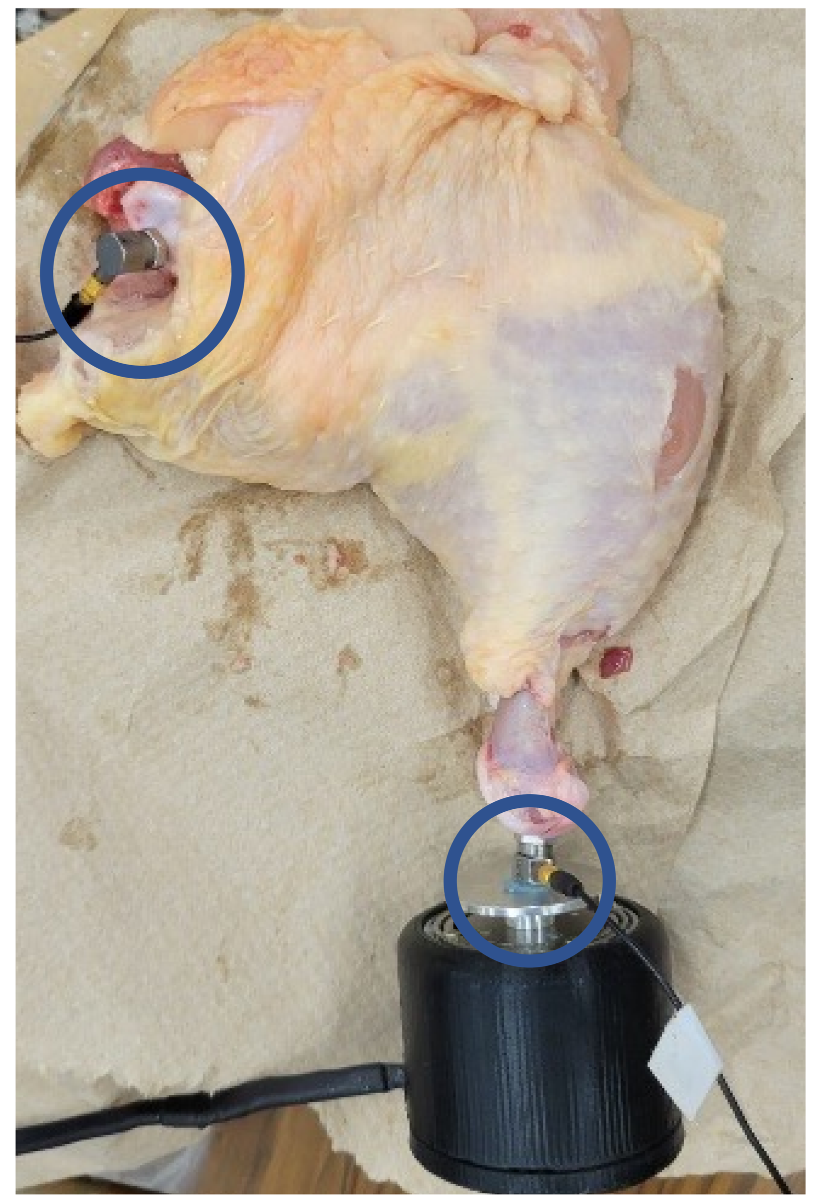


Figure 1. Completely intact chicken knee joint setup. One sensor was placed at the femoral head, and the other at the distal tibia end.

(a) (b) (c)

Figure 2. Degrees of knee joint dislocation (a) partial dislocation (b) foam insertion and (c) complete dislocation

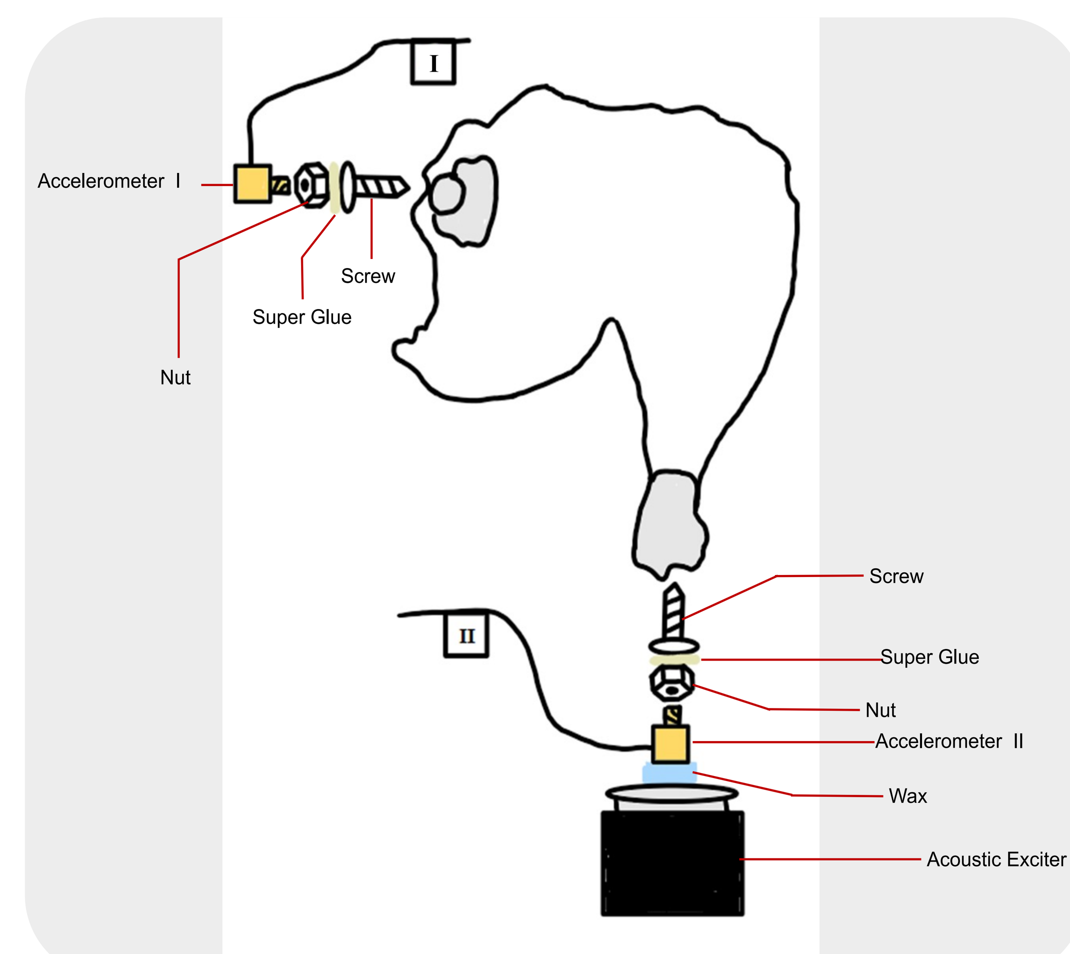


Figure 3. Pictorial description of apparatus setup

Data and Results

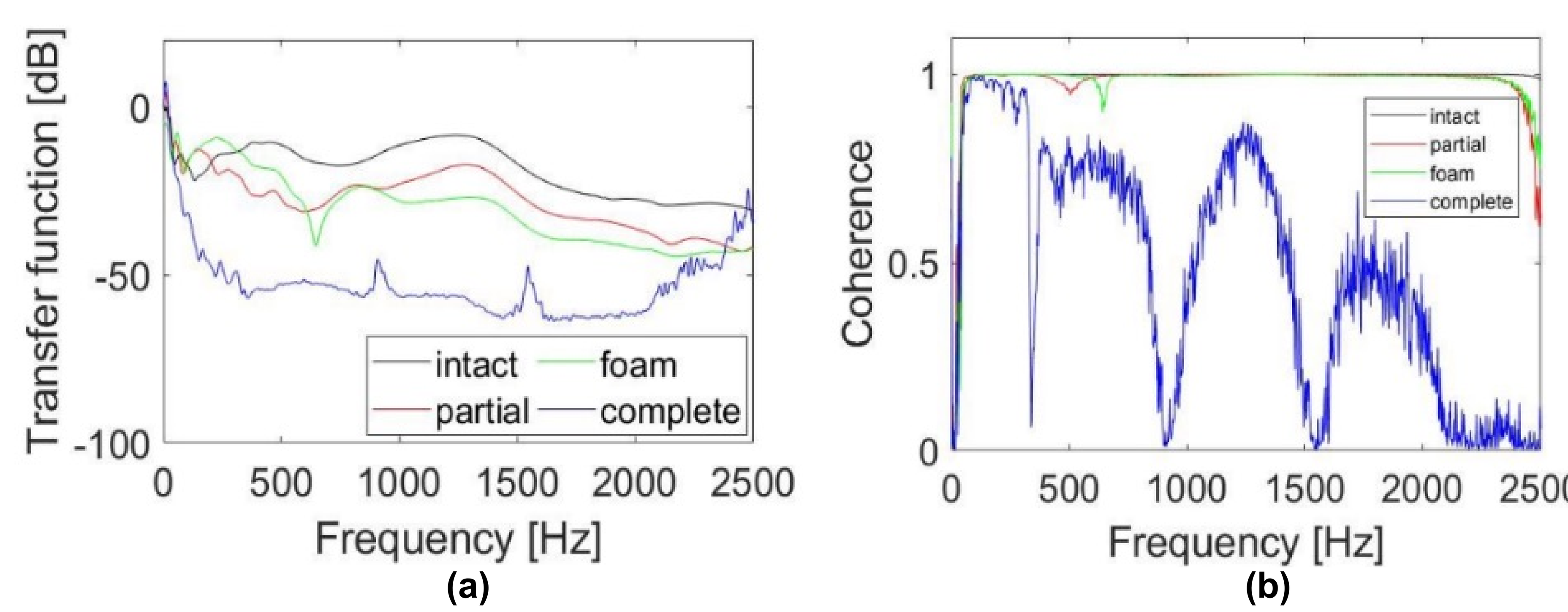


Figure 4. (a)Transfer function and (b) coherence between the stimulus and transmitted signals

Table 1. Mean Drop in Transfer Function from Intact to Partial Cases

Specimens	Mean Drop between 500 - 1100 Hz	Mean Drop between 1101 - 2000 Hz
Shown in Figure	6.268 dB	10.805 dB
All Four Samples (mean ± SD)	8.300 ± 2.199 dB	11.786 ± 3.645 dB

Conclusions

- There was a reduction in transfer function in the complete dislocation case compared to the intact case (Figure 4a).
- There was a frequency-dependent loss of coherence with the complete dislocation case (Figure 4b).
- The mean drop in transfer function between intact and partially dislocated cases was smaller (with smaller variability) between 500-1100 Hz and higher in the 1101-2000 Hz range. Minimal changes were seen for frequencies < 150 Hz. This suggests that current stimulus frequencies (50-2500 Hz) may be useful for DDH screening.
- Therefore, if these preliminary studies are replicated in actual infants with and without DDH, acoustic transmission transfer function and coherence may prove to be effective, non-invasive and rapid screen for DDH in infants
- Limitations of the current study include:
    - Differences between the chicken joint and infant hips
    - The nature of the DDH distraction used in this model, which included air or foam interface in the distracted joint space
    - The application of the sensors to exposed bones rather than through overlying skin and soft tissue which would be the case with infants.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. FW-HTF-P 2026516. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] S. Yang, N. Zusman, E. Lieberman, and R. Y. Goldstein, "Developmental Dysplasia of the Hip," *Pediatrics,* vol. 143, no. 1, 2019. [Online]. *https://pediatrics.aappublications.org/content/143/1/ e20181147/tab-article-info.*

[2] P. Kotlarsky, R. Haber, V. Bialik, and M. Eidelman, "Developmental dysplasia of the hip: What has changed in the last 20 years?" *World Journal of Orthopedics,* vol. 6, no. 11, pp. 886-901, 2015. [Online]. *https://www.wjgnet.com/2218-5836/full/v6/i11/886.htm*

[3] A. Sulaiman, Z. Yusof, I. Munajat, N. Lee, and N. Zaki. "Developmental dysplasia of hip screening using ortolani and barlow testing on breech delivered neonates," Malays Orthopedic Journal, vol. 5, no. 3, pp. 13-16, 2011. [Online]. http://www.morthoj.org/2011v5n3/Dysplasia_Hip_Screening_Ortolani_Barlow.pdf

[4] B. A. Shaw, and L. S. Segal, "Evaluation and Referral for Developmental Dysplasia of the Hip in Infants," *Pediatrics,* vol. 138, no. 6, 2016. [Online]. *https://pediatrics.aappublications.org/content/ early/2016/11/17/peds.2016-3107/tab-article-info.*

[5] T. Hassan, L. Mckinney, R. Sandler, A. Kassab, C. Price, F. Moslehy, and H. Mansy, "An Acoustic Approach for Detection of Developmental Dysplasia of Hip," *2018 IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*, Philadelphia, PA, USA, 2018. *https://ieeexplore.ieee.org/document/8615627*

[6] T. Hassan, *Detection of DDH in Infants and Children Using Audible Acoustics*, M.S. dissertation, Dept. Mech. and Aerospace Eng., University of Central Florida, Orlando, Florida, USA, 2019. *https://stars.library.ucf.edu/etd/6750/*

[7] T. Hassan, L. Mckinney, R. Sandler, A. Kassab, C. Price, F. Moslehy and H. Mansy, "A System for Measuring Sound Transmission Through Joints," *2019 IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*, Philadelphia, PA, USA, 2019. *https://ieeexplore.ieee.org/document/9037844*

[8] T. Hassan, R. Sandler, C. Price, A. Kassab and H. Mansy, "Detecting Hip Dysplasia Using Acoustic Excitation in a Pig Model," *2020 IEEE Signal Processing in Medicine and Biology Symposium (SPMB)*, Philadelphia, PA, USA, 2020, pp. 1-3. *https://ieeexplore.ieee.org/document/9353621*

[9] M. Geswell, N. Sinha, M. Mandel, B. Wheatley, W. Mirenda, and M. Seeley, "Improving resident education through unstable chicken hips: a novel way to teach an infant hip examination," *Journal of Pediatric Orthopedics*, 2020. [Online]. *https://journals.lww.com/jpo-b/Abstract/2021/03000/Improving_resident_education_through_unstable.8.aspx/*

[10] T. M. Tamer, ""Hyaluronan and synovial joint: function, distribution and healing," *Interdisciplinary Toxicology*, vol. 6, no.3, pp. 111-125, 2013. [Online]. *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3967437/#CIT0090.*