A Chicken Model for Acoustic Detection of Developmental Hip Dysplasia

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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).

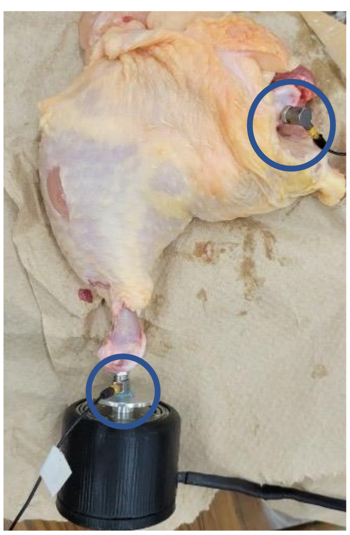
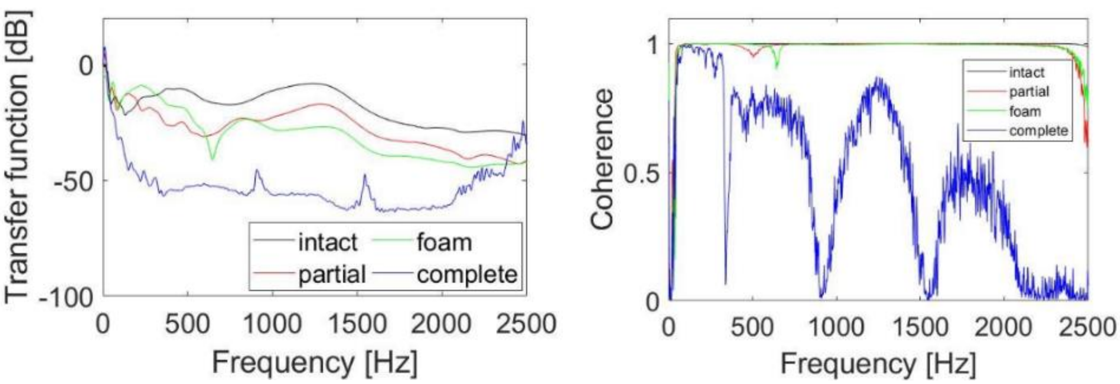


Figure 1. The completely intact knee joint setup. One sensor was positioned at the femoral head, and the other at the distal end of the tibia.

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.

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