From Northern Ireland

Vibration Emission in Detecting Congenital Dislocation of Hip

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This is a preliminary report of a unique method of detecting abnormalities in neonatal hip joints. The method to be discussed is harmless, noninvasive and objective. It is designed as an aid in deciding if the neonate has a dislocated or dislocatable hip soon after birth.

Early Diagnosis, An Enigma

The early diagnosis of congenital dislocation of the hip remains an orthopaedic enigma. Prior to Ortolani's test,[1] clinical diagnosis was based on the presence of abnormal skin creases, limb shortening, restricted hip abduction, presence of telescoping, and, more usually, by the child walking with a limp.

Radiographs were used to detect acetabular dysplasia and confirm the dislocated or subluxed hip. In the neonate, the clinical signs were unreliable, and Ortolani's test was welcomed as a more accurate indication of a dislocated hip at birth.

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Barlow,[2] with his modification of Ortolani's test, was able to detect neonatal hips that were unstable or dislocatable at birth. Both these clinical tests permitted the age at diagnosis to be decreased so that treatment could be commenced earlier, thus producing a better prognosis for the affected hip.

A number of studies[2-4] confirmed a decrease in the numbers of late congenital dislocation of the hip using these clinical tests. These tests were carried out in single maternity units with a small number of highly trained examiners. Contrary to these reports are the results from studies by Williamson,[5] MacKenzie,[6] and Cowie,[7] which showed no decrease in the numbers of late congenital dislocation of the hip in areas where the population was widespread and the neonates were born in a large number of maternity units where they were examined by medical personnel with widely varying experience.

The problem at present is that clinical tests for congenital dislocation of the hip are extremely subjective, and although they are adequate if performed by experienced examiners, in widespread communities, abnormal hips are missed at birth because of the examiner's inexperience and, thus, the numbers of late congenital dislocation of the hip continue undiminished.

Analysis of Sounds

When neonatal hip joints are tested, the produce sounds: a *click* is felt and heard during Ortolani's test, usually when full abduction is reached, or the classic *clunk* heard, felt, and sometimes seen when a dislocated hip is reduced or an unstable hip subluxates on Barlow's test. The method of detection to be discussed is based on the detection and analysis of these sounds.

Sound is energy that is transmitted by pressure waves in air or other materials and is the objective cause of the sensation of hearing. Sound, however, is only one part of the total vibration spectrum which extends from very low frequencies of vibrations below audible ranges through the acoustic range to ultrasound. Clinical experience has shown that joints emit pressure waves or vibrations which are composed of subsonic frequencies felt as crepitus and some frequencies heard as sound. Vibration emission is the collective name for both these subsonic vibrations and some pressure waves.

Joint auscultation has been studied since the beginning of the 20th century. However, all investigations were carried out using microphones of various kinds to detect the sound. There were, however, problems with this instrument, and it was noted that much of the clinically relevant emission lay in the subsonic range at which level the acoustic microphone was a poor detector. Microphones also picked up an excessive amount of ambient noise.

Experimental work by Mollan,[8] as reported in his thesis *Vibration Emission from Bone and Joints,* helped to pioneer a method of detecting sounds from joints and correlated them with pathologic conditions in joints. Mollan observed that most of the sounds from joints were of low frequency not appreciated by the ear but by vibrations appreciated by the skin pressure sensors on the hand. The response of any acoustic technique system was inaccurate below 50 Hz, and he suspected that a good part of joint emission lay in this area—below the normal acoustic frequency range.

Analysis of acoustic data represented only a part of the total vibratory emission from

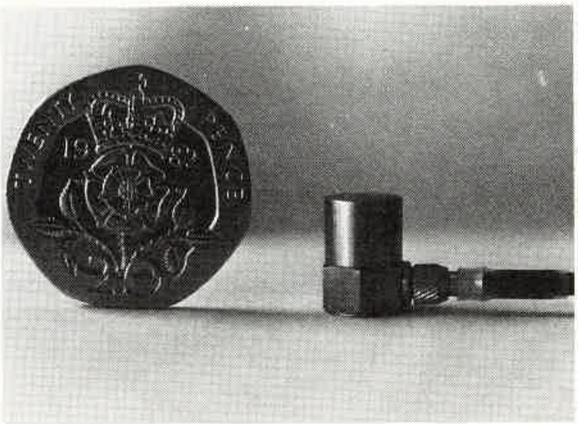

Fig 1. *The accelerometer which proved to be an ideal transducer for detecting vibration emissions from the hip joint. (Its size is compared to a coin.)*

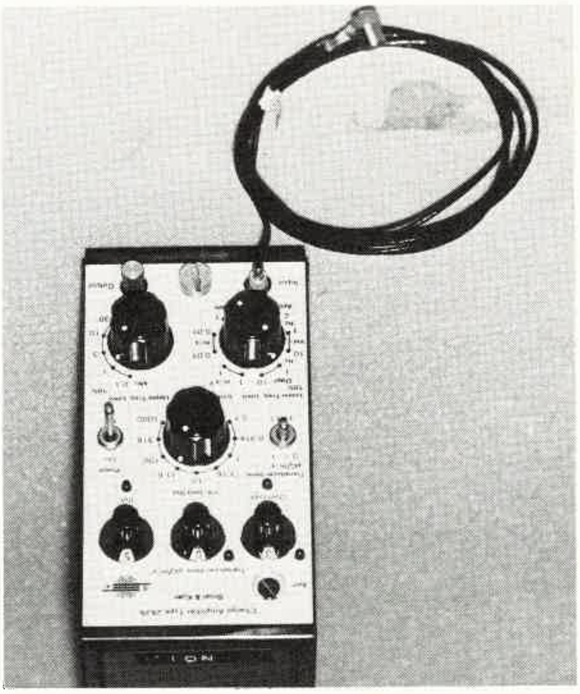

Fig 2. *Piezo-electric accelerometer with charge amplifier to prevent reduction of the signal.*

joints. The investigations indicated that such vibrations were not only random continuous waves but that there were many isolated transient signals which appeared to be the result of pure mechanical impulses from within the joint. These findings imposed strict theoretic limits on the choice of transducer that could be used and confirmed that the microphone measuring only air pressure changes around the joint was not the ideal transducer both in terms of dynamic sensitivity and frequency.

The transducer which seemed most suitable was the accelerometer (Fig 1), an electromechanical transducer that generates an electrical output by means of a piezoelectric response to a mechanical shock or vibration. The accelerometer could be mounted directly onto the skin, and, because of its small size, in theory, no skin movement occurred under the baseplate, thus eliminating the skin friction vibrations.

Method and Material

The vibration emission from the hip joints was detected by accelerometers attached in the region of each anterior superior iliac spine. To prevent reduction of the signal in transfer to the recording device, a preamplifier was required (Fig 2). A charge type of preamplifier was chosen because of the need for long accelerometer output cables. When used in this mode, the capacitance of the cable would not alter the sensitivity of the lower limiting frequency. By this method, the accelerometer was used as a charge source and produced an output voltage proportional to the input charge.

Display of the recordings was by two methods. First, the choice of an analogue print-out of the emission was governed by the need for a four-channel instrument which would respond to rapidly changing signals. The mingograph ink-jet recorder offered the advangage of an instantly visible and permanent trace. This recorder is a standard item

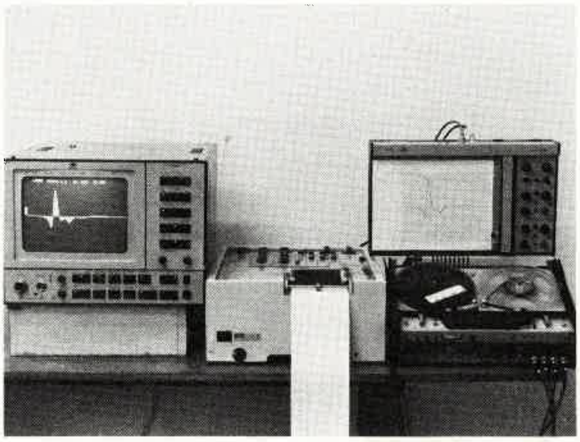

Fig. 3. *Total display unit. Narrow Band Spectrum Analyzer (left); the mingograph (center); and the FM tape-recorder with X-Y plotter (right).*

of hospital equipment for the display of electrocardiograph signals.

Second, a Bruel and Kjaer 2031 Narrow Band Spectrum Analyzer was used to display the time amplitude mode of the vibration signals and a frequency analysis of each sample. Hard copy of the captured signals was produced via the analogue output on a Bruel and Kjaer 2034 X-Y recorder (Fig 3). The actual method of detection was performed as shown in Figure 4.

The accelerometer was attached to the neonate just behind the anterior superior iliac spine. A third accelerometer was placed on a board on which the neonate lies during testing. This accelerometer was in contact with the neonate's sacrum and detected emissions from either hip joint. With a relaxed neonate, the routine clinical tests of Ortolani and Barlow were performed, noting the presence or absence of sounds either heard or felt.

Two groups of children were initially tested. The first group was composed of 30 neonates with a *click* who were referred for screening from the maternity units of hospitals in Belfast. These infants were tested on site within the first five days of birth.

The second group consisted of eight children who were having their hips reduced in surgery after an adductor tenotomy. Each

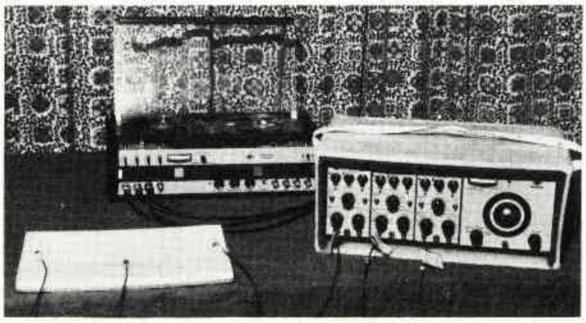

Fig 4. *The actual equipment that was used for screening. On the left is the board with the three accelerometers on which the neonate lies during the screening procedure.*

Table 1
Three Artifact Groups

Source	*Artifact*
1. **Skin/Transducer**	i Movement of transducer relative to the skin
	ii Gross movements of the limbs
	iii Clothing impacts
	iv Building oscillations
	v Direct impacts
2. **Signal Transmission**	i Cable impacts
	ii Cable whipping
	iii Cable vibration transfer
	iv Loose connections
3. **Signal Processing**	i Pre-amplifier overload
	ii Pre-amplifier filtering

emission was correlated with the x-ray image intensifier screening of the hips to correlate the vibration signals with reduction and dislocation. This group consisted of late dislocations of the hip missed at birth. At reduction, they produced the *clunk* sound.

One neonate was screened who had an unstable/dislocatable hip at birth, producing the *clunk*.

The vibration emission technique, however, was not devoid of artifact.[9] Artifact could be divided into three groups, depending on its source, as shown in Table 1. All sources of artifact were investigated by recording them and then displaying them via the ink-jet recorder and Narrow Band Spectrum Analyzer for analysis.

Results

When screened by our method, the 30 neonates produced a total of 26 *clicks* on clinical testing. The waveform produced by one of these *clicks* is shown in Figure 5. This is how they are displayed on the ink-jet recorder.

Analysis on the Narrow Band Spectrum Analyzer produced a frequency spectrum for the *click* as shown in the lower half of Figure 5. The peak frequency value of the spectrum was the parameter in which we were interested.

In the *clicks* group, the waveform varied from *click* to *click* in different children. When testing a child with repeated *clicks,* the waveforms of such *clicks* also varied from one to the other, ie, there was wide variation in waveform.

The peak frequency values also varied in this group with a mean frequency of 169 ± Hz. In the neonate with repeating *clicks,* the

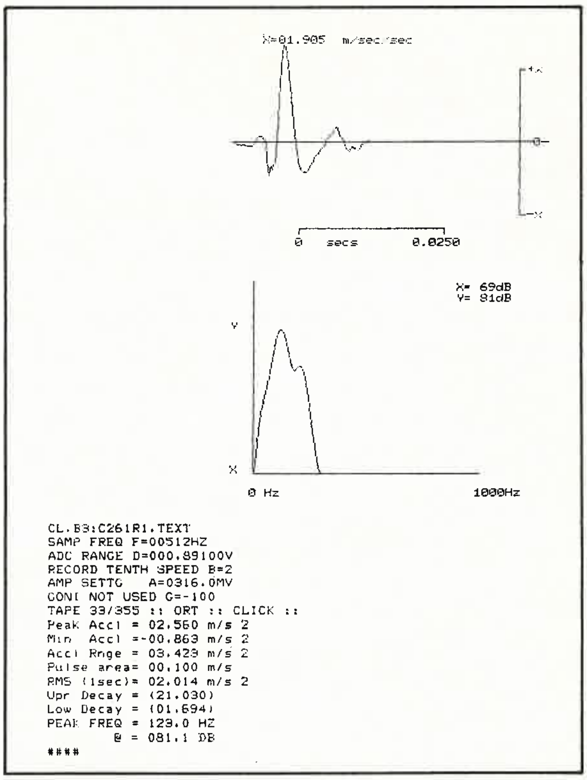

Fig 5. *A click waveform and frequency analysis.*

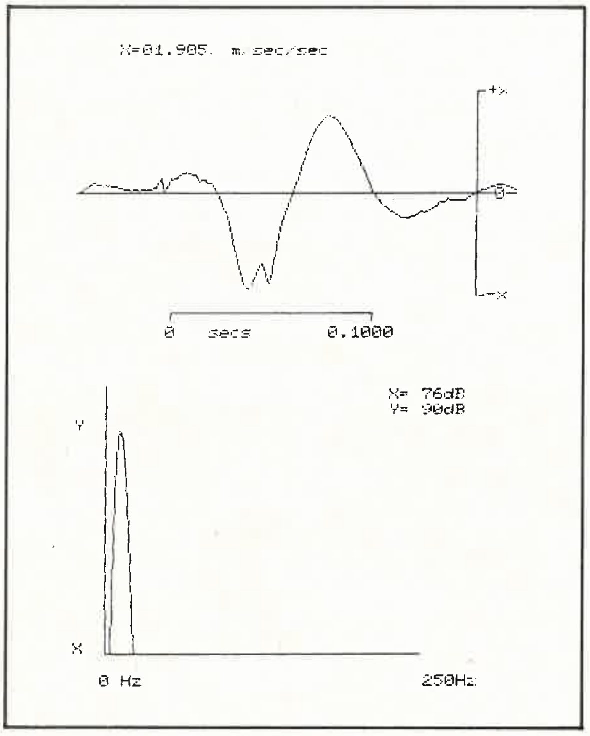

Fig 6. *Clunk from late congenital dislocation of the hip and the waveform and frequency analysis that it produced.*

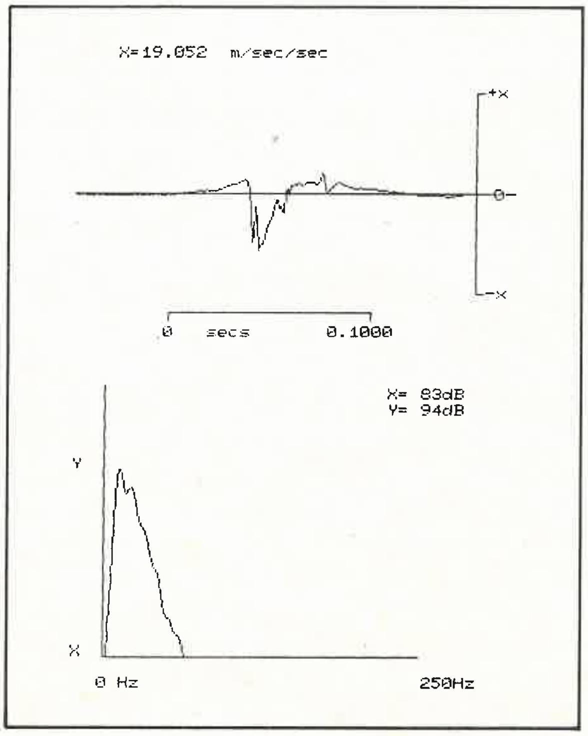

Fig 7. *Clunk from unstable hip and the waveform and frequency analysis that it produced.*

peak frequencies also varied widely from 70 Hz to 212 Hz.

A *clunk* from the late dislocation group produced a waveform as shown in Figure 6. All of the group produced similar waveforms, and when the test was repeated in one individual, almost identical waveforms were produced. Peak frequency analysis produced a range of 7.5 Hz to 25 Hz, with a mean value of 12.5 $\pm$ 2.5 Hz.

The single unstable hip at birth produced a waveform as shown in Figure 7. The peak frequency on analysis was 12.5 Hz.

Discussion

This method permits, for the first time, objective differentiation between the *click* and *clunk* heard during clinical testing of neonatal hips. The waveforms of the two sounds are clearly different: the *click* being a burst of energy or impulse released during normal movement of the femoral head in the acetabulum. This noise may be due to a build-up of negative pressure during movement which is suddenly neutralized, leading to cavitation emission from the joint. (An analogy is the rubber sucker being pulled off glass.)

The *clunk* is a low frequency vibration and is produced by the femoral head sliding back into the acetabulum. This emission is almost certainly due to two cartilage/bone interfaces striking each other, whereas the *click* is due to a pressure change at a gas/solid interface.

As the waveforms differ, so do the other parameters, including the peak frequency. The *clunks* are a clearly defined group, as the small range of the peak frequency values indicate. The *clicks* are more heterogenous, as indicated by the wide range of peak frequency values. However, this parameter clearly differentiates the two signals. This wide range of peak frequencies produced by *clicks* is being further investigated.

At present, the method and equipment used are time-consuming, hard to work, and expensive. To make it a more suitable aid to the inexperienced examiner, we are working on two developments. One is a wider study of neonates who have either *clicks* or *clunks*. The other is to simplify both the detection system and the display storage and analysis system.

Summary

We present a harmless, noninvasive method of detecting the emissions from neonatal hips during clinical testing. This method clearly differentiates between the pathologic *clunk* and probably innocuous *click*[10] in two ways—waveform and peak frequency value.

With further investigation, this method will be an objective aid to the inexperienced examiner and will help detect abnormal hips at birth that are at present being missed. In this way, hopefully, the incidence of late congenital dislocation of the hip will be decreased.

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