Feasibility of Using Ultrasonic Emission for Clinical Evaluation of Prosthetic Hips

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Abstract

Background: Previous acoustic emission (AE) studies of the hip have proposed using AE for the diagnosis of musculoskeletal conditions and assessing the clinical status (loosening, wear, etc.) of prostheses. However, these investigations have had problems with spurious signal noises or complicated measurement techniques, or both.

Purpose: We performed a study on 98 patients to evaluate the feasibility of employing ultrasonic emission (UE) to determine total hip arthroplasty (THA) status, using a simple, hand-held measurement system that has addressed some of the prior problems with hip AE studies.

Methods: UE was recorded from both hips of study patients during walking and sitting activities. The patients had 79 metal-on-polyethylene implants, and at least 15 each with ceramic-on-polyethylene, ceramic-on-ceramic and metal-on-metal articulations; 10 young subjects without THA were similarly recorded as controls. Data were obtained from waveform analysis and standard UE signal parameters. Patient radiographs were evaluated for THA status, and wear measurements were made for metal-on-polyethylene articulations.

Results: There were distinct types of UE waveforms produced; one was typical of the control subjects as well as some patients. We did not find an apparent relationship among these waveform types and type of THA bearing, length of implantation or wear measurements in the metal on polyethylene bearings.

Conclusions: Our results suggest that it maybe possible to assess the status of THA by UE signals, but further studies are necessary to quantify this finding. The clinical relevance of this investigation is that a simple, in-office screening means for THA patients could indicate those patients who require closer follow-up and monitoring.

The analysis of hip joint vibrations by various techniques (phonarthrography, vibration arthrometry, vibroarthrography, hip auscultation) has been explored as a means to assess joint pathologies, disease status, and, recently, incipient prosthesis failure. Frequencies lower than 100 Hz have been used to diagnose gross pathology and wear in knee prostheses; frequencies from 1 k to 10 kHz, development and progression of osteoarthritis; and frequencies greater than 10 kHz, loosening of cemented hip prostheses. A recent study used frequencies less than 10 k in an attempt to distinguish between different bearing materials and to examine sonic output as a function of the gait cycle. It is possible that detailed analysis of higher frequencies, greater than 20 kHz, could detect and quantify the smaller geometric changes (asperities) that develop in prosthetic articular wear. These higher frequencies also have the advantage in that ambient noises and noises from skin or muscle movements do not confound analysis.

We used a simple technique to measure ultrasonic emission (UE) from the hips of patients with a variety of total hip arthroplasty (THA) implants, in an attempt to see if emission signals were related to the type of implant or duration of implantation, and to discern if there was any relationship of emission signals to the apparent amount of wear in metal-on-polyethylene THA.
Materials and Methods

This Institutional Review Board (IRB)-approved study examined UE generated by various types of hip prostheses on 98 patients [average age, 60.7 years (range, 28 to 87); gender, 50 males and 48 females]. Patients were directly recruited by their physicians and evaluated during regularly scheduled follow-up appointments. Patients were told that this was a basic research study and provided an explanation of its methods and aims and that participating in the study had no effect on their treatment and no direct benefit to themselves, nor would there be any costs or payments to the patient. All patients recruited signed an IRB approved consent.

Patients had an ultrasonic transducer [W-40 microphone; Physical Acoustics Corporation (PAC), Princeton Junction, New Jersey] attached to their skin over the greater trochanter with a 3M Tegaderm™ hypoallergenic transparent dressing using a standard acoustic coupling gel layer on the microphone face to improve skin contact. The transducer was attached by a 2 m cable to a battery-operated data recorder-logger (PAC AE-1, Fig. 1).

After being fitted with the equipment, patients were asked to sit in a chair, rise, sit again, and then rise and take five steps while the acoustic data was recorded separately from the two movements of sitting and walking. This procedure was then repeated for the opposite hip.

The data was de-identified by the surgeons for any subsequent analysis, with only patient sex, age, weight, height, type of prosthesis, and the duration of prosthetic implantation being included. Ten volunteers [average age, 26.5 years (range, 23 to 33)] who had no hip problems or

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**Figure 1** Patient testing procedure showing microphone attached over the trochanter with a disposable dressing; microphone is attached by cable to the recorder.

**Figure 2** Types of emission waveforms. Type A, Smooth waveform curve (typical of normals, hip simulator tests, and some THA patients). Type B, Some degradation of signal. Type C, Further degradation of signal. Type D, Complete degradation of signal.
pain issues were used to obtain control UE data from both hips in a similar manner.

We also used the equipment to record data from new metal-polyethylene and ceramic-ceramic hip prostheses by attaching the microphone to the test chambers of a multi-station hip joint simulator (MTS® Systems Corporation, Eden Prairie, Minnesota). This bench testing was performed at 1 Hz, with cyclic, physiologic loading applied axially, to a maximum load of 2450 N and lubricated with distilled water.

Our emission analyses also examined frequency distribution(s) and power spectrums of the recorded signals and their relations to prosthesis bearing type and implantation time. Data was analyzed by AEwin™ Windows software (Physical Acoustics Corporation, Princeton Junction, New Jersey). Although the software can provide over 600 different output graphs, the graphs and resulting data for analysis were chosen from studies on AE of wear couples9 and a previous pilot study using this hip simulator.10

Routine radiographs of 50 of the patients with metal-on-polyethylene total hips, taken at the time of their follow-up visit, were analyzed to quantify the amount of polyethylene wear in millimeters, using the simple method of scribing circles centered over the prosthesis head and acetabular cup and measuring the distance between their centers. Statistical analyses were performed using STATA (StataCorp LP, College Station, Texas).

Results
From the patients studied (some with bilateral prostheses), we obtained data on 79 metal-on-polyethylene (average follow-up, 8.7 years; range, 0.1 to 28), 20 ceramic-on-ceramic (average follow-up, 5.0 years; range, 0.5 to 10), 17 metal-on-metal (average follow-up, 1.2; range, 0.1 to 5.5), and 15 ceramic-on-polyethylene (average follow-up, 0.6 years; range, 0.1 to 1) THA articulations, as well as 75 hips with no implants that had various degrees of osteoarthritis. For the following analyses, the total hips were grouped only as generic bearing types, without reference to specific type or size of prosthetic components or fixation means. Figure 2 represents the typical waveform outputs showing voltage (mV) as a function of time that we classified as Types A-D depending on the appearance of the curve.

It should be noted that these waveform graph types were similar for walking and sitting. For an individual patient, however, these two activities could often produce different waveform behaviors, possibly reflecting that different surfaces of their hip are articulating with different biomechanical loadings and motions while walking or sitting. Those patients who had no pain and hips without a prosthesis (similar to our normal subjects) usually had hips demonstrating a different waveform type (A) than those patient’s hips with painful osteoarthritis (C or D); initial findings suggest that osteoarthritis severity might be quantified. For those hips without a prostheses, 39/75 were type A, as were 9/10 of our normal subjects; the two types of new hips tested in the hip simulator also showed a type A waveform.

The number of signal waveform types A and B during walking for the four THA bearing types are given in Table 1. An analysis of homogeneity by Fisher’s exact test showed no significant (p > 0.32 for all) differences among these THA groups with respect to waveform type distributions. Similar results were obtained from sitting activity. There also appeared to be no relation of waveform curve type to total prosthesis implantation time (types converted to ordinal, linear values; r = 0.103).
A graph of signal intensity (walking) versus implantation time is shown in Figure 3. It is representative of other parameter plots derived from the original patient data recordings in that there appears to be no relation \((r = 0.027)\) to the time the prosthesis had been implanted.

The measurements of wear of the metal on polyethylene prostheses obtained from patient radiographs are given in Table 2 as a function of waveform type. An analysis of homogeneity showed no significant differences \((p > 0.24\) for all) between the waveform curve type and amount of wear.

**Discussion**

We found that a simple qualification of the basic waveform recording appeared to suggest there was a waveform type typical of young, normal hips and new implants (simulator) that was observed in some of the THA patients. Various degrees of degradation of this waveform were observed in the rest of the patients as well as changes in other AE parameters. These waveform types did not appear related to the general type of bearing articulation; however, specific parameters such as prosthesis design, type of polyethylene, ceramic or metal, and bearing size were not analyzed due to the fact that in some cases these were unknown, and where known, the sample size was too small for meaningful comparison. For the metal-on-polyethylene prostheses, it was thought that an increased time of implantation might lead to increased wear that could possibly be reflected by changes in the AE parameters. Although no relationship was seen, this might again be a factor of polyethylene type, bearing size, or factors such as patient weight or activity. Although our wear measurement was not as precise as other techniques,\(^1\) we felt it was adequate for our purpose. Another explanation is that the signal might not be related to linear or volumetric wear but a surface phenomenon that has a much shorter initiation time.

**Conclusion**

Our data suggest that it may be possible to assess the clinical status of THA by UE signals. Additional analysis of clinical data and of quantified wear couple testing on a hip simulator will be required to more accurately qualify and quantify the results of this promising new test methodology.

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