RESEARCH ARTICLE

Intraoperative Acoustics: Auditory Cues in Hip Reconstructive Surgery

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Abstract

Background: Orthopaedic surgeons rely on visual and tactile cues to guide performance in the operating room (OR). However, there is very little data on how sound changes during orthopaedic procedures and how surgeons incorporate audio feedback to guide performance. This study attempts to define meaningful changes in sound during vital aspects of total hip arthroplasty (THA) within the spectrum of human hearing.

Methods: 84 audio recordings were obtained during primary elective THA procedures during sawing of the femoral neck, reaming of the acetabulum, acetabular cup impaction, polyethylene liner impaction, femoral broaching, planning of the femoral calcar and press-fit of a porous-coated stem in 14 patients. We graphed changes in frequency intensity across the human spectrum of hearing and sampled frequencies showing differences over time for statistically meaningful changes.

Results: Sawing of the femoral neck, polyethylene impaction, and stem insertion showed significant temporal increases in overall sound intensity. Calcar planing showed a significant decrease in sound intensity. Moreover, spectrographic analysis showed that, for each of the critical tasks in THA, there were characteristic frequencies that showed maximal changes in loudness. These changes were above the 1 dB change in intensity required for detection by the human ear.

Conclusion: Our results clearly demonstrate reproducible sound changes during total hip arthroplasty that are detectable by the human ear. Surgeons can incorporate sound as a valuable source of feedback while performing total hip arthroplasty to guide optimal performance in the OR. These findings can be extrapolated to other orthopaedic procedures that produce characteristic changes in sound. Moreover, it emphasizes the importance of limiting ambient noise in the OR that might make sound changes hard to distinguish.

Level of evidence: IV

Keywords: Acoustics, Arthroplasty, Hip, Performance, Sound

Introduction

Orthopaedic surgeons integrate multiple simultaneous sources of information in the operating room (OR) to guide technical performance. Sources can include tactile feedback, radiographic images, as well as direct visualization of involved structures. Of the five senses, sight and touch are clearly very critical, and for some circumstances such as infection, smell can be very important. To date, the

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utility of sound as a source of sensory feedback in the OR has received little attention in the literature.

An experienced orthopaedic surgeon should utilize all forms of sensory feedback to optimize outcomes effectively, including sound. Some studies have addressed the impact of high background noise volumes in the OR, suggesting that increased noise may act as a distraction or may even cause auditory discomfort at high volumes (1,2). The OR is often a noisy environment due to conversations, noise from surgical and anesthesia equipment, music, and alarms. Before measuring the impact of this ambient noise during surgery, it is important to quantify the actual sounds produced by the procedure itself and subsequently determine whether the human ear can appreciate them in a useful manner.

Few studies have addressed the auditory changes that occur during orthopaedic procedures, let alone the potential for surgeons to utilize said changes to guide performance. Some studies have investigated the correlation between changes in sound and adequacy of stem fit during the broaching stage in total hip arthroplasty (THA). Others have reported certain frequency changes during the broaching process as being indicative of an impending fracture (3-5). There is no literature to our knowledge on the presence of distinct patterns of sound during the other main stages of THA. If we can utilize sound to perform procedures more accurately, then the next logical step is to optimize the OR environment to take advantage of this feedback.

The purpose of this study is to measure how sound changes in the OR during vital aspects of THA in order to find meaningful changes in sound character. We hypothesize that auditory feedback in this setting can be characterized and quantified with statistical differences.

Materials and Methods

We selected patients undergoing primary elective THA at random from the schedule of two orthopedic surgeons for inclusion in this study. Audio recordings were obtained during sawing of the femoral neck, reaming of the acetabulum, acetabular cup impaction, polyethylene liner insertion and impaction, femoral broaching, planing of the femoral calcar and press-fit of a porous-coated stem. The microphone was held four feet from the incision site, near the patient's head [Figure 1]. OR personnel were advised to refrain from speaking to prevent disclosure of private health information (PHI). If we deemed a recording to contain PHI, it was immediately deleted from the device.

Recording was completed using a Rode® NTG1 Shotgun microphone (Rode Microphones, Sydney, Australia) and Tascam® DR-40 pulse code modulation digital recorder (TEAC Corp. Montebello, CA). Analysis of the audio tracks was completed on a personal computer using Audacity®, an open-source audio editing and analyzing software available at https://www.audacityteam.org

We represented recordings qualitatively in the form of an audio spectrogram. Data from spectrogram plots was analyzed quantitatively using statistical methods to compare changes in decibel (dB) levels across frequencies over time. We analyzed overall dB changes for each step, as well as identified specific frequencies within each step that showed the most statistically significant change. A total of 128 frequencies for each recording were analyzed.


Figure 1. Intra-operative recordings were obtained four feet from the incision site near the patients head.

Of note, increased sound intensity, as measured in dB, is perceived as an increase in loudness by the human ear. The human ear is capable of detecting changes in dB levels to varying degrees depending on factors such as age and prior sound exposure. Even so, the "just noticeable difference" in perceived loudness is as low as 0.5 dB in the average listener (6, 7). For the purpose of this study, we used 1dB as the cutoff for a noticeable difference.

Our Institutional Review Board reviewed the study protocol and granted approval prior to initiation of the study.

Results

A total of 84 audio spectrograms were analyzed from fourteen elective THA procedures. The average age of the patients was 73.57 years (range 61 to 86 years). 3 patients were male (21%), and 11 were female (79%). We obtained recordings from 12 anterior (86%), and 2 lateral approach surgeries (14%).

Overall, sound intensity (dB) from beginning to end of each step of THA was compared [Table 1]. Sawing of the femoral neck, polyethylene impaction, and stem insertion all showed significant increases in sound intensity(loudness) from beginning to end. Planing of the femoral neck showed a significant decrease from beginning to end. Acetabular reaming, cup impaction, and femur broaching did not show a significant change in overall sound intensity from beginning to end.

In addition to analyzing overall sound change, we identified and compared the frequencies that had the most significant change in sound intensity from the beginning to the end of each step of the procedure. A surgeon would perceive these frequency changes as an alteration in tone as well as loudness. Sawing of the

Table 1. Average dB for each step of the procedure

Surgical Tasks	**Beginning (dB) Mean [95% CI]**	**End (dB) Mean [95% CI]**	***P value***
Sawing Neck	-54.86 [-61.94; -48.38]	-50.62 [-59.26; -43.89]	<0.001*
Acetabulum Ream	-73.55 [-80.23; -69.11]	-77.18 [-81.96; -70.92]	0.059
Cup Impaction	-49.92 [-56.51; -42.56]	-49.78 [-57.37; -41.23]	0.768
Polyethylene Impaction	-52.17 [-58.72; -43.53]	-48.43 [-55.75; -40.86]	0.002*
Femur Broach	-58.22 [-65.31; -47.56]	-55.38 [-63.06; -43.71]	0.052
Femoral Calcar Planning	-76.69 [-81.62; -66.61]	-79.91 [-84.23; -67.86]	0.004*
Stem Insert	-61.22 [-67.80; -52.32]	-57.24 [-63.15; -47.60]	<0.001*

CI=Confidence interval; dB=Decibel.
* Statistically significant differences between the two groups (p<0.05)

femoral neck showed the most significant changes at 344 Hz, 516 Hz, and 1205 Hz with dB changes of 8.3, 7.7, and 7.0, respectively (*P=0.003*). Acetabular reaming showed the most significant changes at 516 Hz, 689 Hz, 11,714 Hz, and 11,886 Hz with dB changes of 7.6, 5.4, 5.1, and 5.1, respectively (*P=0.003*) [Figure 2]. Cup impaction showed the most significant changes at 172 Hz, 344 Hz, and 861 Hz with dB changes of 3.1, 2.5, and 2.7, respectively (*P=0.003*) [Figure 3]. Polyethylene insertion and impaction showed the most significant changes at 689 Hz, 861 Hz, and 1033 Hz with dB changes of 7.0, 8.1, and 7.3, respectively (*P=0.002*). Broaching of the femoral canal showed the most significant changes at 861 Hz, 1033 Hz, and 9130 Hz with dB changes of 5.2, 5.4, and 5.3, respectively (*P<0.001*) [Figure 4]. Planing of the femoral calcar showed the most significant changes at 3789 Hz, 3966 Hz, 4651 Hz, and 4823 Hz with dB changes of 5.7, 5.4, 5.3, and 5.3, respectively (*P<0.001*). Lastly, the stem insertion showed the most significant changes at 689 Hz, 861 Hz, and 21,533 Hz with dB changes of 8.0, 7.6, and 7.4, respectively (*P=0.001*) [Figure 5].

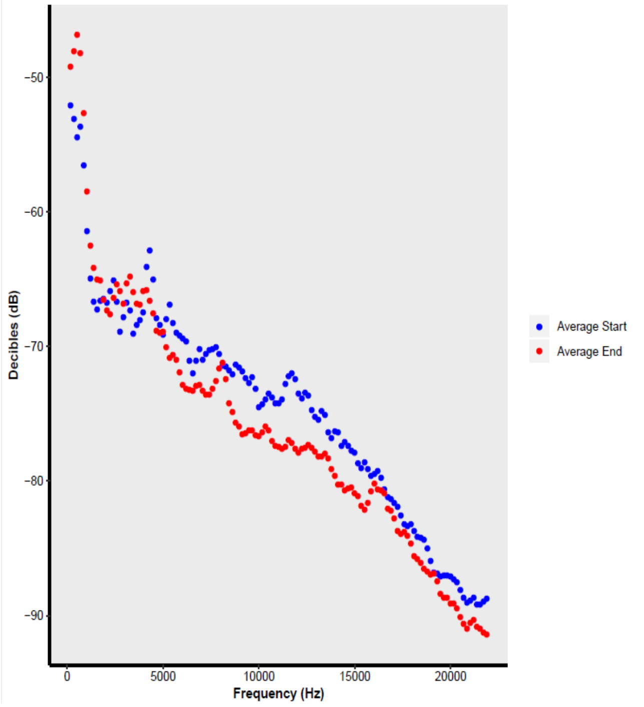

Figure 2. Scatterplot depicting changes in sound intensity (in decibels) in response to frequency changes at start and end of acetabular reaming. Hz=Hertz

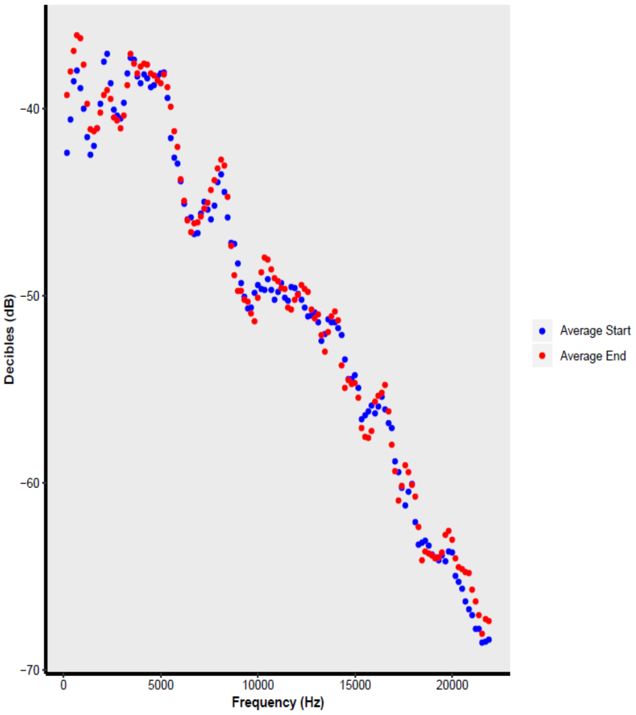

Figure 3. Scatterplot depicting changes in sound intensity (in decibels) in response to frequency changes at start and end of cup impaction. Hz=Hertz

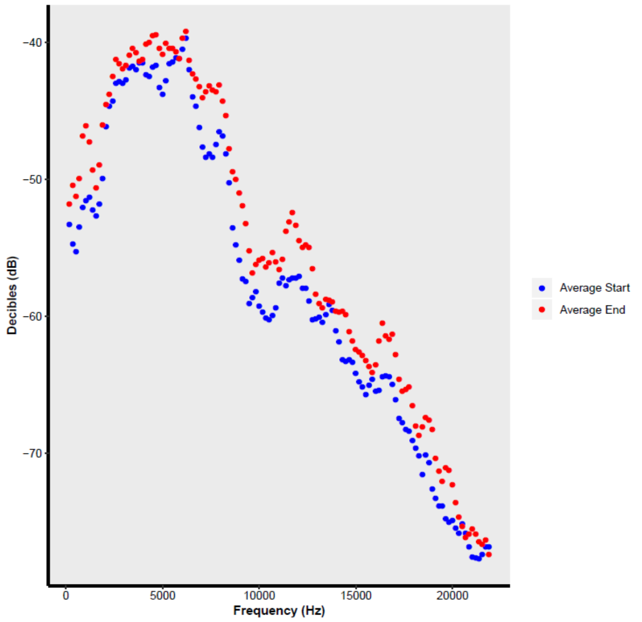

Figure 4. Scatterplot depicting changes in sound intensity (in decibels) in response to frequency changes at start and end of femur broaching. Hz=Hertz

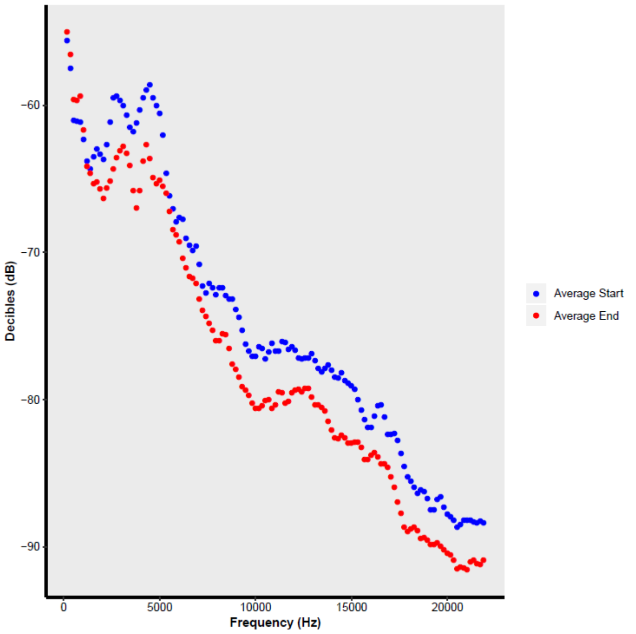

Figure 5. Scatterplot depicting changes in sound intensity (in decibels) in response to frequency changes at start and end of stem insertion. Hz=Hertz

Discussion

The use of auditory feedback to guide performance is not a novel concept, nor is it limited to the field of surgery. For centuries, musicians have trained their ears to detect small changes in sound intensity across the spectrum of sound. A musician's livelihood depends on their ability to adjust the "timbre" of their instrument, both for aesthetic appeal but also to find their place within a concert of sound (8-10). Needless to say, humans are remarkable in their ability to incorporate and react to auditory feedback.

Examples of the use of auditory feedback to guide performance are very common. Engineers may use acoustic feedback to find worn or defective rolling element bearings, since smooth bearings produce less intense and more uniform sound compared to worn bearings, which will produce an irregular, loud noise (11). In the 1950's-80's German car mechanics perceived the automobile as a "sounding object", listening for characteristic changes in sound to diagnose the cause of a failing engine (12). Before the advent of stud-finders, contractors used their bare knuckles to tap on drywall until they found the characteristic "thud" of a supporting two-by-four beam just behind it (13). Finally, within the field of medicine, cardiologists rely on the stethoscope to listen to changes in the sound character of a patient's heart. A louder "thud" indicates a thickened valve, while "whooshing" sounds represent fluid turbulence, possibly due to regurgitation through an incompetent valve. A cardiologist's ability to detect aberrant sounds, ultimately leads to higher quality care for their patients.

To our knowledge, this is the first study to characterize changes in sound character during major steps in THA. Our results show statistically significant increase in sound intensity(loudness) during a number of these steps. The majority of changes exceeded the 0.5-1.0 dB minimal threshold necessary for human detection as shown in psychoacoustical experiments for average healthy humans (6, 7, 14). Although these thresholds may not be valid at extremes of frequency or loudness (frequencies less than 125Hz and greater than 8000Hz and sound pressure levels greater than 100dB, tasks that were analyzed in this study demonstrated changes in frequency and loudness that were well within these extremes (14).

One of the findings that was apparent during this study was that as the surgeon performed each of the assigned tasks, there was commensurate increase in loudness. The explanation for this change is that bony resonance escalates as surgical tools increase contact surface area with bone. This finding is similar to that of McConnell et al., who reported an association between low-frequency sound made during the broaching process and femoral length, concluding that this sound change is a good predictor of adequate stem fit (3). Although their goal was to identify sound changes to predict correct stem sizing specifically in the broaching process, their findings indicate that there are distinct differences in sound resulting from bone-metal interactions that may be identifiable to the surgeon during other stages of the procedure.

Noise levels in the OR can be very high, especially during orthopaedic procedures where use of power tools and impaction instruments is common. Various studies have measured sound intensity in the operating room to determine if noise exposure is a possible occupational health hazard for surgeons (15-22). Most studies find that average sound levels are at acceptable levels.

However, peak values can often exceed 100dB and even approach levels as high as 131dB which may pose risks according to Occupational Safety and Health Association standards for acceptable exposure (17,19,21). As previously discussed, our ability to perceive changes in sound is diminished at such high levels, which is another reason to decrease sound levels in the operating room.

There has been much investigation on the distracting effects of loud noise on surgeon performance and outcomes (1, 2, 23). A study by Way et al. reported that OR noise could reduce auditory processing, increasing the risk of miscommunication (24, 25). Moorthy et al. stated that surgeons are able to "block out" noise during procedures, likely due to the high level of concentration needed for the procedure (26, 27). However, while physicians may be able to filter out ambient noise to focus on the physical task, our results imply that processing some of these sounds may be helpful in their goal. Therefore, these extraneous noises in the OR have the potential to cause additional harm by interfering with the perception of characteristic changes in sound. Praamsma et al. found that distracting noise negatively affected drilling depth in orthopedic surgeons, showing that the surgeon relies on the sounds being produced by the instrument to determine position in the bone (2). Kam et al. showed that several sources of noise in a given space lead to reduced ability to distinguish/discriminate between which are important (e.g., those relating to the surgery) and which are extraneous (noises from other persons in the OR, etc.) (28). For one particular patient in our study, the surgeon stopping striking during polyethylene cup impaction to check proper seating after a perceived change in sound; this change was depicted by spectral analysis as an increase in sound intensity in the 7.5KHz to 8.5 KHz range [Figure 6]. Our results imply that

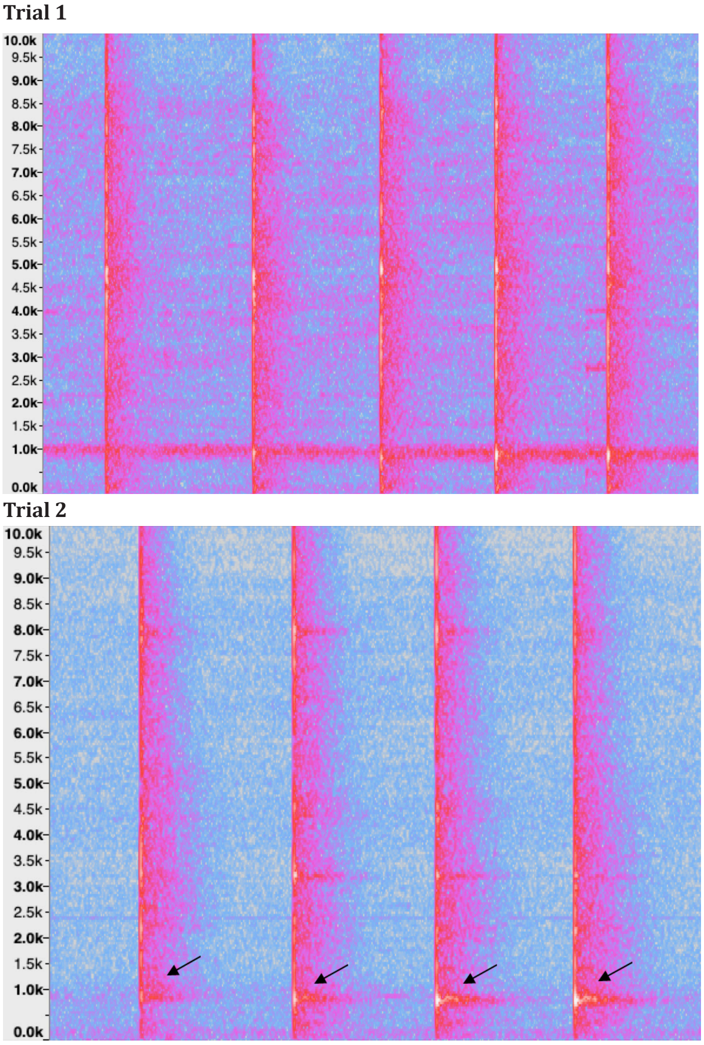

Figure 6. Audio spectrogram during two different instances of polyethylene cup impaction. Red lines indicated a strike of the polyethylene cup impactor. In Trial 2, notice the gradual increase in sound intensity at the 7.5KHz to 8.5 MHz range (arrow) with each successive strike. This change was not observed in Trail 1. During Trail 1 the surgeon stopped to check proper seating of the polyethylene cup and found it to be, in fact, loose. The surgeon attempted to reinsert the cup, as show in Trial 2, after which the cup was found to be securely in place. The increase in sound intensity in this case was found to be statistically significant.

orthopedic surgeons should be able to train themselves to detect subtle nuances in sounds during a THA with the suggestion that this could potentially have an effect on overall outcomes. In order to optimize this, it is logical that extraneous noise may need to be minimized as much as possible, so as not to interfere with auditory feedback.

There are several limitations to our study. First, only one procedure was chosen for this initial investigation, so it is not possible to say whether the results would be the same for other orthopaedic procedures. Second, we recorded the steps after instructing all personnel in the OR to limit their noise as much as possible. However, it is possible that some background noise (e.g., OR personnel and or instrument movement) was picked up by the recorder and incorporated into our data. The recorder was positioned close to the instrumentation relative to any other sources of noise, so if any additional sounds were picked up, the effects on our data was likely to be very small. Finally, the lack of outcome data from these patients restricted our ability to correlate the changes in intensity to surgical outcomes, including complications such as fracture or implant dissociation as well as ultimate implant survival.

This study shows that sound changes in meaningful ways during one common orthopaedic procedure. Moreover, these changes are within a range that can be discerned by the human ear and would be perceived as changes in tone and loudness. Future studies are necessary to quantify the ability of surgeons to utilize these auditory cues to improve performance as well as mitigate the effect of ambient noise on the process. If auditory feedback can influence surgical outcomes, then surgical environments should be modified to maximize these effects. Additionally, auditory training could be incorporated into orthopaedic residency training programs to produce better surgeons.

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