The Risk of Noise-Induced Hearing Loss Performing Knee Replacement Surgery

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Abstract

Objective: Powered surgical instruments use to cut bones and fashion them for joint implant produce noise. Prior studies have not analyzed direct in vivo measurements of multiple procedures and exposure time. This study evaluates actual surgical noise levels exposure to the surgeon and this cumulative exposure that can result in noise-induced hearing loss (NIHL). What is known: Prior studies evaluated short duration noise exposure to surgical equipment in vitro, or in an operating room environment. What this adds: This study evaluated in vivo cumulative measurements over an entire operating day and the associated risks. Methods: Noise exposure to operating room personnel was measured during multiple knee replacement surgeries over three days. Measurements were compared to occupational exposure limits set by the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA). Results: Surgeons’ noise exposures exceed noise occupational exposure limits. Recorded levels of 104 dBA did occur with levels of 85dBA found from 10-18% of the time. Conclusions: Surgeons performing multiple total knee replacements per day are at risk of NIHL due to noise exposures that exceed National Institute for Occupational Safety and Health recommendations. Surgeons should be included in a hearing loss prevention program. Level of Evidence: Therapeutic Level 1

Keywords: Hearing loss, noise-induced, occupational noise, total knee replacement,

INTRODUCTION

Orthopaedic surgery that involves joint replacement requires the use of powered saws and drills to prepare and fashion the femoral and tibial bone ends to accept the new implant. These tools are typically high-powered, hand-held battery-operated devices that allow the surgeon to make precise geometric cuts for the new prosthesis.

The number of total knee replacements performed has grown from slightly over 400,000 in 2003 to an estimated 1 million in 2015. This number is expected to grow to nearly 3.5 million by 2030, due to the needs or desire of people to maintain an active lifestyle or to co-morbidities that predispose patients to arthritis. As the number of knee arthroplasties has increased, workloads of orthopaedic specialists have also increased. Many specialty physicians will schedule eight or more joint replacements in a single work period.

Prior studies evaluating noise exposures during surgeries have evaluated distant noise levels across a variety of different surgeries, subjectively evaluated operating personnel’s perception of noise, or have evaluated diverse orthopaedic equipment and were not specific to total knee arthroplasty. This study characterized and evaluated full-shift and task-based time-weighted average (TWA) noise exposures to surgeons and operating room personnel during standard primary total knee joint replacement.

Additionally, this study included left and right ear noise measurements to compensate for the surgeon’s head position and handedness. The personal noise measurement periods included time spent outside the surgical suite. These measurements, along with noise...
measurements during surgery, allowed an assessment to be made concerning the impact of the number and length of surgeries, as well as shift length on the potential for excessive noise exposure.

MATERIALS AND METHODS

The National Institute for Occupational Safety and Health (NIOSH) Health Hazard Evaluation (HHE) program was contacted out of concern about noise exposure during total knee surgery. The employer requested an evaluation due to the potential for NIHL among surgical staff. During its evaluation, NIOSH researchers visited the hospital three times over a sixth month period to evaluate surgical team members’ exposure to noise. The visits occurred between June and December 2017. The visits were performed during elective morning surgical time between 7 AM and noon.

The primary goal of the evaluation was to assess full-shift personal noise exposures of surgical staff. Secondary goals included (1) assessing noise levels during surgeries and during non-operating times, (2) evaluating the difference in exposure between the left and right side measurements, and (3) estimating noise exposure ranges using a mathematical model.

Work activity

During three visits, two Board Certified and experienced senior surgeons performed primary total knee surgeries on 11 patients. Both surgeons used identical Stryker System 6 saw systems and drills for each case. The saw blades used were Deupy Synthes joint blades (article number 05.003.114S, cutting thickness 1.19 millimeter).

All surgical procedures involved primary cemented total knee replacements which included the femur,ibia, and patella. The six male patients’ average age was 63.7 years of age (range: 58–73 years), and the five female patients’ average age was 67.6 years of age (range: 45–83 years). All cases were for the condition of osteoarthritis. There was no history or evidence of metabolic bone disease. The patients had no co-morbidities that would affect bone density.

Surgeries occurred in three different operating rooms. Each room was similar in size and design. The floors were vinyl with drywall ceilings and walls. An established sterile field extended approximately five feet on either side of the patient. A plastic sheet barrier separated the anesthesiologist from the sterile field. The surgery and method of draping was the same for each patient.

Noise sampling methods

Personal full-shift and task-based TWA noise exposures were measured using Larson Davis Spark™ model 706RC integrating noise dosimeters. These devices integrated noise at a 50-hertz sampling rate and data-logged one-second average noise levels. The dosimeters simultaneously measured noise using three different settings to permit comparison of results with three different noise exposure limits: the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 90 decibels.[7]

The surgeon, the surgical assistant (the fellow or first surgical assistant), and the anesthesiologist participated in personal noise exposure monitoring. In addition, the time spent in surgery and outside of surgery was tracked. Dosimeters were worn at the waist and the microphone was attached on the outside of the gown or scrub midway between the shoulder and neck. The microphone was covered with a windscreens to eliminate artifact noise caused by bumping or rubbing. Surgeons each had two dosimeters with a microphone placed on each shoulder to compare whether left and right ear noise exposures differed. These measurements were compared using the Student’s paired t-test. The noise measurement data were downloaded using the PCB Piezotronics™ Blaze program.

Estimating noise exposure ranges

Estimated ranges of time-weighted average, (TWA) noise exposures for surgeons were modeled (Equation 1) to determine the potential for over exposure to noise. The estimates were based on the following variables: Number of surgeries, surgical noise level, nonsurgical noise level, surgery duration, and shift length.

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\text{SurgeonsTWA noise exposures} = 10\log_{10} \left( \frac{1}{W} \left( \left( \left( \frac{N}{T} \right) \left( 10^{5.5/2} / 10 \right) \right) + \left( \left( W - \left( \frac{N}{T} \right) \right) \left( 10^{5.5/2} / 10 \right) \right) \right) \right)
\]

where \( W = \) length of work shift (minutes); \( N = \) number of surgeries performed; \( T = \) time per surgery (minutes); \( S_{avg} = \) measured TWA noise level during surgery (dBA); \( NS_{avg} = \) measured TWA noise level during nonsurgical periods (dBA)

Equation 1. Model for estimated range of full-shift noise exposure for surgeons performing arthroplasty

RESULTS

Full-shift TWA personal noise exposure measurements of surgical staff, summarized in Table 1, showed that surgeons had the highest noise exposures. The surgical assistant and anesthesiologist had the lowest personal noise exposures, and all of their full-shift noise exposures were below 80 dBA. All surgical staff full-shift noise exposures were below noise exposure limits, except one surgeon’s full-shift noise exposure was above the NIOSH recommended exposure limit, (REL). The highest recorded level was 104 dBA during any procedure. Comparison of surgeons’ right side versus left side noise measurements showed that their noise...
measurement results were significantly higher \((P = 0.04)\) on the right side measurement versus the left side measurement, on the basis of NIOSH noise measurement criterion.\(^7\) Exposures on the left and right sides were not significantly different on the basis of OSHA noise measurement criterion.\(^7\)

A time-history profile for one of the surgeons on one of the days of noise dosimetry monitoring shows noise exposures during four surgeries and noise exposures between surgeries [Figure 1]. Noise levels during surgeries reached 90 to 100 dBA intermittently during surgical tool use. These were above the NIOSH REL level of 85 dBA; noise levels between surgeries were less than 85 dBA most of the time.

Figure 1 shows the duration of surgeries and the range of surgeons’ task-based noise exposures during surgeries and during the time between surgeries. Surgical duration ranged from 49 to 113 minutes and varied depending on the surgeon. Overall, surgeons spent 54–72% of their work shift in surgery. On each day of monitoring, the surgeons completed four surgeries with TWA noise levels during surgery ranging approximately from 82–89 dBA, on the basis of NIOSH noise measurement criteria. Surgeons’ task-based noise exposures were substantially higher during surgery than during their time outside surgery. Outside of surgery, task-based noise exposures ranged approximately from 75–82 dBA [Table 2]. A histogram of the surgeons’ and the surgical fellow’s noise exposures as a function of percent of total time during surgery is shown in Figure 4. Noise exposures were above 85 dBA for 10–18% of the time and were above 90 dBA for 5–7% of the time. Noise exposures were below 80 dBA for a majority of the work shift, ranging from 59–84% of the time [Figure 2]. Equation 1 was used to estimate surgeons’ full-shift exposure estimates for several scenarios using the range of noise exposure measurement results during surgery, noise exposure outside of surgery, shift length, surgery length, and number of surgeries. Figure 5 shows the estimated range of TWA noise exposure during a 10-hour surgical day, for surgical

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**Table 1: Summary of surgical staff full-shift time weighted average noise exposure measurements**

| Job title                              | Number of measurements | NIOSH REL criterion (dBA) | OSHA AL criterion (dBA) | OSHA PEL criterion (dBA) |
|----------------------------------------|------------------------|---------------------------|-------------------------|--------------------------|
| Surgeon (right shoulder measurement)  | 3                      | 81.4–86.8                 | 76.5–83.5               | 68.1–78.2                |
| Surgeon (left shoulder measurement)   | 3                      | 77.9–83.2                 | 71.3–77.9               | 62.3–73.0                |
| Surgical fellow (right shoulder)      | 1                      | 81.5                      | 74.3                    | 70.4                     |
| Surgical fellow (left shoulder)       | 1                      | 83.0                      | 75.6                    | 72.5                     |
| Surgical assistant                    | 3                      | 76.0–78.7                 | 64.2–70.8               | 58.2–65.4                |
| Anesthesiologist                      | 2                      | 67.8–71.8                 | 58.2–75.8               | 38.4–46.1                |
| Noise exposure limits (8-hour work shift) |                        | 85                        | 85                      | 90                       |

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**Figure 1:** Time history profile showing a surgeon’s noise exposure (outlined in boxes in figure), on the basis of National Institute for Occupational Safety and Health, noise measurement criterion, during four knee replacements.
Table 2: Surgeons’ and surgical fellow’s time-weighted average noise exposure results during surgical and nonsurgical periods

| Surgeon/Fellow | Task duration (minutes) | NIOSH relative exposure limit criterion (dBA) | OSHA acceptable limit criterion (dBA) | OSHA permissible exposure limit (dBA) |
|----------------|-------------------------|---------------------------------------------|---------------------------------------|---------------------------------------|
| Surgeon A      | Surgery (n = 4)          | 50–69                                       | 86.2–89.2                             | 83.6–86.4                             | 76.8–82.8                             |
| January 13, 2015 | Not in surgery           | 199                                         | 81.6                                  | 78.0                                  | 66.2                                  |
|                 | TWA noise exposure       | 432                                         | 86.8                                  | 83.5                                  | 78.2                                  |
| Surgeon A      | Surgery (n = 4)          | 49–74                                       | 81.9–84.0                             | 76.6–80.7                             | 70.6–72.9                             |
| January 20, 2015 | Not in surgery           | 190                                         | 76.2                                  | 70.5                                  | 48.3                                  |
|                 | TWA noise exposure       | 444                                         | 81.4                                  | 76.5                                  | 68.1                                  |
| Surgeon B      | Surgery (n = 3)          | 64–113                                      | 84.0–85.3                             | 78.6–79.9                             | 74.9–76.7                             |
| July 22, 2015   | Not in surgery           | 100                                         | 77.5                                  | 72.4                                  | 53.1                                  |
|                 | TWA noise exposure       | 357                                         | 83.8                                  | 78.0                                  | 74.0                                  |
| Surgical fellow | Surgery (n = 3)          | 64–113                                      | 81.3–86.1                             | 74.4–79.0                             | 71.2–77.6                             |
| July 22, 2015   | Not in surgery           | 140                                         | 75.1                                  | 68.5                                  | 47.1                                  |
|                 | TWA noise exposure       | 397                                         | 83.0                                  | 75.6                                  | 72.5                                  |

Figure 2: Histogram of the surgeons’ and surgical fellow’s noise exposures during surgeries.

Figure 3: Range of surgeons’ estimated noise exposures for a 10-hour work shift on the basis of the range of noise levels, duration, and number of surgeries performed.
Similarly, Kamal[5] demonstrated minor hearing loss in hearing loss in half of 22 orthopedic personnel having transient peak noise levels during hip and knee surgeries.

Knee replacement surgeries.[8] Although the percentage of powered instruments were used 4% of the time during surgical instruments. Other studies have similarly shown levels were generated primarily during use of powered instruments. 

Time-history data showed that noise levels were above 90 dB for 7% of the time during surgery. These high noise levels were generated primarily during use of powered surgical instruments. Other studies have similarly shown that powered instruments were used 4% of the time during knee replacement surgeries.[8] Although the percentage of time noise levels exceeded 90 dBA was relatively low, because noise is measured on a logarithmic scale, levels at and above this have a profound effect on overall noise exposures.

Our observations during knee replacement surgery revealed that surgeons used saws, drills, and hammers intermittently, multiple times for 1–30 seconds during each use. Dosimeter time-history data showed that noise levels were above 90 dBA for 5–7% of the time during surgery. These high noise levels were generated primarily during use of powered surgical instruments. Other studies have similarly shown that powered instruments were used 4% of the time during knee replacement surgeries.[8] Although the percentage of time noise levels exceeded 90 dBA was relatively low, because noise is measured on a logarithmic scale, levels at and above this have a profound effect on overall noise exposures.

Several researchers have shown noise levels ranging from 90–110 dBA near surgeons during use of reciprocating saws.[5,8,10,11,12,13,14] Additionally, research has shown that sound levels from operating room instruments such as drills, hammers, and suctions ranged 78–103 dB.[12,13,15] Fritsch et al.[11] reported that sound levels from operating room equipment ranged from less than 90 dB from carbon dioxide lasers to greater than 130 dB from nitrous oxide hoses. His study was not directed at a specific procedure nor analyzed the cumulative noise dose. He noted that there was a risk from instrument noise, but did not specify the procedures at highest risk. We found that peak sound levels during surgery ranged from 131–138 dB. Other researchers have also measured peak levels above 130 dB. Love[10] measured transient peak noise levels during hip and knee surgeries ranging 128–146 dB; however, the surgeons in that study did not use the modern saws and reciprocating systems that were used in this study.

Sydney et al.[17] compared sound levels from the modern saw blade with an oscillating tip to a conventional blade in which the entire blade oscillated. Measurement results collected during simulated surgeries in a laboratory found that sound levels averaged 88.9 using a conventional blade but were reduced to 81.6 dBA using the modern blade. Peters et al.[18] also compared sound levels from these two types of saw blades, but during actual total knee arthroplasty surgeries performed by two experienced surgeons. He found a greater reduction of sound levels using oscillating tip blades; ranging from 93.1 dBA using conventional blades to 84.4 using one type of oscillating tip blade and 81.3 using a different oscillating tip blade. The authors noted that full-shift noise exposures after using the conventional blade system, but not the oscillating tip blade system, during three 90-minute surgeries would exceed the Dutch ARBO (Dutch OSHA) recommendation of 80 dBA. The results of these two studies support the use of modern oscillating tip saw blades to reduce surgical noise.

Surgeons’ full-shift TWA, noise exposures varied from 78–87 dBA (based on NIOSH measurement criterion), which reflect differences in the noise levels during surgeries and total length of time spent in surgery. Noise exposures outside of surgery had very little effect on full-shift exposures. None of the surgeons’ noise exposures were above the OSHA REL level and allowable limit (AL), but one of the surgeon’s exposure was above the NIOSH REL level. Surgical staff typically assisted on fewer surgeries than the surgeons performed, spending less time in high noise areas. Noise exposures for surgical staff were well below exposure limits. NIOSH researchers have similarly found low exposures among surgical staff during a previous evaluation.[19] Although not measured, the patients’ noise exposures were likely to be similar or less than the anesthesiologists’ ones. Katz[9] noted that a patient’s stapedius muscle, which helps protect the inner ear from loud sounds when contracted, is relaxed during anaesthesia and could put the cochlea at risk in anaesthetized patients.

Depending on the noise exposure during surgery and total time in surgery (a product of number of surgeries and length of each surgery), this evaluation demonstrated that surgeons’ noise exposures could exceed the NIOSH REL with as little as two total knee replacement surgeries during a shift. Surgeons’ potential for overexposure increases with the noise level during surgery and the number of surgeries performed in a single shift.

Measurements taken on the surgeons’ right shoulder were significantly higher than left shoulder measurements. This was presumed to be due to the handedness of the surgeons, as both were right handed. In all surgeries, the powered instruments were held in the right hand, closer to the right ear. This study highlights the potential for exceeding the
NIOSH REL and the associated increased NIHL risk among the operating surgeon. NIOSH estimates that workers exposed to an average daily noise level of 85 dBA over a 40-year working lifetime have an 8% excess risk of material hearing impairment. This excess risk increases to 25% for an average daily noise exposure of 90 dBA.[7]

Protection strategies should include the use of devices that attenuate noise. This noise reduction should not be excessive as this could interfere with necessary communication in the operating room. Flat-attenuation earplugs, which reduce noise evenly across all frequencies and have a low noise reduction rating, or earmuffs with electronic noise cancellation features are potential hearing protection options.[11] In addition, surgeons should be included in a hearing loss protection program which provides yearly audiometric evaluations.

Limitations of this research include a small number of surgeons and days of monitoring. Additionally, only one type of powered surgical tool system was used. Further research and noise measurements on other powered surgical tools and during more knee replacement surgeries would allow for more complete characterization of noise exposures.

CONCLUSION

Powered surgical instruments are the primary sources of noise during total knee replacement surgeries. The sound exposure during knee replacement can exceed the NIOSH REL level. All other surgical staff noise exposures were well below noise exposure limits. Being exposed to noise above the REL level, increases surgeons’ risk for NIHL. Noise exposures and hearing loss risk could be reduced by using flat attenuation earplugs or noise cancellation earmuffs. In addition, surgeons whose noise exposures are potentially in excess of the NIOSH REL should be included in a hearing loss prevention program.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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