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Noise exposure on surgeons using robotic surgical equipment for total knee arthroplasty

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ABSTRACT

Objectives: Occupational noise is a major issue in orthopedic surgery due to the prevalent use of power tools. In recent years, there has been a tremendous increase in the usage of robotic surgical equipment (RSE) in health care. One disadvantage of using RSE is the exposure to high noise levels for those in the vicinity of the robot. This study assessed noise levels associated with the Mako robotic surgical system in the performance of total knee replacement (TKR) surgeries.

Methods: Noise measurements were conducted using a dosimeter in the orthopedic operating room (OR). The maximum peak noise level (LCpeak) and the equivalent continuous noise level (LAeq = average sound level for a period of time) for each activity or piece of equipment were determined to estimate the daily dosage of noise (LEX, 8h) for OR personnel. Noise levels were assessed with reference to occupational noise regulations in Australia.

Results: The Mako robotic system produced the highest LAeq (89.5 dBA), while the maximum peak noise level was recorded during the use of the hammer (126.6 dBC). The surgeon was found to be exposed to the highest average sound level (LAeq), maximum peak noise level (LCpeak), and greatest daily dosage of noise (LEX, 8h).

Conclusion: As noisy equipment and instruments are used intermittently, the noise regulations were technically not exceeded when averaged throughout the session. However, noise levels in the OR were sufficiently high to warrant consideration of hearing protection for OR personnel during total knee arthroplasty, particularly for sessions where multiple surgeries are undertaken.

Keywords: Arthroplasty, Noise, Replacement Knee, Robotics, Surgical equipment

INTRODUCTION

Occupational noise is a pervasive issue across various sectors, including health care. Noise can be defined as any general unpleasant or disturbing sensation that is produced by any acoustic phenomenon.[1] Prolonged exposure to unwanted sounds causes adverse health effects.[2] The characteristics of noise associated with deleterious health effects are typically determined by its intensity (loudness) and duration of exposure. It has been shown that prolonged or excessive exposure to noise has damaging health effects both psychologically and physiologically.[3] Thus,

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noisy or excessively loud workplaces may result in various adverse health outcomes, the most prominent being "Noise-Induced Hearing Loss" (NIHL).

Usually, NIHL results in a temporary shift in hearing levels that can recover within 24 h under quiet conditions.[4] However, with sustained exposure, the cochlear hair cells may become permanently damaged, resulting in permanent sensorineural hearing loss. This affects the ability to perceive higher-pitched sounds, typically falling within the range of 3000–6000 Hz, thereby gradually impairing effective communication, especially in social settings.[5] Occupational noise has been estimated to account for approximately 10% of the burden of adult hearing loss in higher-income countries.[6]

Another deleterious effect of occupational noise exposure is the development of tinnitus (buzzing or ringing in the ears), which may produce psychological as well as physical distress. Other psychological effects, such as stress, can also develop over time from repeated noise exposure. It has been suggested that this might potentially lead to cascading effects such as reduced immune system responses, reduced concentration/performance, and difficulty sleeping.[7] Noise has also been linked to an increased risk of cardiovascular diseases and hypertension.[8]

Occupational noise poses a significant issue for orthopedic operating room (OR) personnel, with the prevalent use of power tools in many orthopedic procedures. In particular, surgeons are regularly exposed to high levels of noise during surgical procedures. In 1991, Willet estimated that 50% of orthopedic personnel were affected by NIHL due to the types of equipment and instruments that are used for general orthopedic operating procedures.[9] Equipment such as drills, power saws, hammers, and others tend to produce sound levels above 90 dBA. Even brief exposure to noise at this level can lead to NIHL.[10]

This study focused on measuring noise that orthopedic surgeons are exposed to while using Mako robotic surgical equipment (RSE) for total knee replacement (TKR).

MATERIALS AND METHODS

We measured and assessed the noise levels to which the surgeon and assisting nursing staff were exposed from noise generated by the Mako robotic system during an operating session. Three "Type 4448" Brüel Kjær (B&K) Dosimeters were used to measure on-site noise [Figure 1]. A windshield was used to obtain better sound recording quality. This dosimeter is designed to be attached to the shoulder using the provided mountings (a choice between alligator clips or safety pins) (User Manual - Personal Dose Meter Type 4448, 2016) as per standard guidelines (AS/NZS 12.69.1 Occupational Noise Measurement and Assessment of Noise Emission and Exposure) and to maintain sterility of the operative field.

Figure 1: Type 4448' Brüel & Kjær (B&K) Dosimeters.

The microphone was mounted on the operator's side, facing the noise source directly (User Manual - Personal Dose Meter Type 4448, 2016). For example, if the RSE is located on the surgeon's left side, then the dosimeter is attached to the surgeon's left shoulder.

Measurements were obtained from microphones worn by the surgeon and the scrub nurse. The dosimeter worn by the surgeon assessed the typical noise levels experienced near the tools and the patient. The one worn by the scrub nurse measured the noise dosage for personnel within the surgical field, but further away (1–2 m) from the noise sources.

Figures 2 and 3 illustrate the dosimeter placement, which was worn on the shoulder under the operator's sterile gown. While the additional layer of the sterile surgical gown may potentially interfere with the noise levels measured, a study by Goffin *et al*. found minimal differences between noise exposure between hooded and non-hooded personnel.[11] As the cloth material for the hood and surgical gown are similar, if not identical, it is likely that the readings from the dosimeter are minimally affected by the additional layers.

The dosimeter program was set up on the Protector Type 7285 software. The dosimeter was set to the default Calibration Level (94dB), and the International Organization for Standardization (ISO) was used for Display Mode (LAeq and LCpeak are used).

The noise levels associated with surgical tools/equipment were assessed individually. As per Safe Work Australia Occupational Health and Safety (SWA OHS) standards, the regulation states that where the maximum and minimum sound levels of a task differ by more than 3dB, then at least one of the following requirements must be fulfilled:

Figure 2: Red arrow depicts the position of dosimeter.

Figure 3: The dosimeter is worn on the shoulder under the sterile surgical gown.

- The task is to be broken down into shorter and smaller tasks
- A total of six measurements for each activity are performed
- Measurements are repeated with a longer averaging/measurement time (User Manual - Personal Dose Meter Type 4448, 2016).

Therefore, measurements were obtained from 6 total knee arthroplasty (TKAs) to ensure that each task had a minimum of 6 measurements. As per Australian SWA OHS regulations, the allowable noise standard is 85 dBA averaged over an 8-h (LEX, 8 h < 85 dbA). In addition, a maximum noise level of 140 dBC (LCpeak) is allowed (Noise: Safety Basics - WorkSafe, 2021).

A surgical session consisted of two TKA procedures with a break between surgeries. The duration of surgery was recorded for each TKA (From initial skin incision to wound closure). Start and end times for breaks were also recorded. Three operating sessions were measured to satisfy the ISO requirements for task-based measurements.

Post-processing

On-site noise measurement data were transferred from the dosimeter to a computer device using the infrared download adapter and Bluetooth dongle. "Work Noise Partner" (one of the recommended software for Type 4448) was used for post-processing.

The following tasks were identified during TKA, Mako robot bone resection, Handsaw bone section, hammer, diathermy, suction, drill, and breaks (excluding lunch).

RESULTS

A total of 8 sets of measurements over 3 days were taken in the OR. Each day consisted of two TKAs (6 cases) with a break between surgeries. Dosimeter recordings were obtained for 6 TKAS from the surgeon and 5 TKAs from the scrub nurse.

The Mako robotic system, the handsaw, and the hammer produced the highest noise levels in the OR. The Mako robot produced the highest LAeq at 89.5 dBA on average. Noise measurement by activity during TKA is shown in Table 1.

Having comprehensively measured the noise output of each instrument and the average duration of their use during a single TKA, we were able to estimate the LEX, 8h, with the assumption of consistent instrument usage across most knee replacements per day. Estimation of noise calculation for multiple TKR in 1 day by extrapolating the data is shown in Table 2.

DISCUSSION

The Mako produced the highest LAeq, 89.5 dBA on average, and the hammer produced the highest LCpeak, 126.6 dBC. The surgeon was exposed to the highest LAeq and LCpeak for each activity. The surgeon was exposed to the highest LEX, 8h, at 77.8 dBA on average amongst all noise environments.

According to SWA OHS standards, the LEX, 8 h Limit (dBA) should not exceed 85 decibels. Thus, the SWA LEX, 8 h recommended maximum, was not breached. However, this study observed a LEX, 8 h of 77.8 dBA for a day, including two TKA surgeries. Additional surgeries per day would almost certainly result in a breach of SWA OHS standards LEX, 8 h limit of 85 decibels. It would seem prudent, therefore, to implement additional controls in the OR to mitigate these risks to OR personnel as well as to patients. Similar results were also found in a study by Goffin *et al.*,

Table 1: Noise measurement of equipment (activity) during TKA.

Activity	Surgeon		Scrub nurse	
	Average LAeq (dBA)	LCpeak (dBC)	Average LAeq (dBA)	LCpeak (dBC)
Mako	89.5	120.8	78.5	111.3
Handsaw	82.9	118.5	75.3	113.9
Hammer	78.1	126.6	71.5	119.6
Various (Diathermy, suction, Drill, etc.)	71.7	123.5	69.1	122.7
Break	66.7	112.6	76.2	123.8

TKA: Total knee arthroplasty, LAeq: Average sound level for a period of time, LCpeak: Maximum peak noise level, dBC: Decibels relative to carrier, dBA: A-weighted decibel.

Table 2: Estimation of noise calculation for multiple TKA in 1 day by extrapolating the data.

Number of TKA cases in a day (surgeon)	LEX, 8h (dBA)
1	74.9
2	77.9
3	79.7
4	80.9
5	81.9
6	82.7

TKR: Total knee arthroplasty, LEX: Daily exposure of noise, dBA: A-weighted decibel.

where noise measurement in 19 TKR done using MAKO exceeded the lower exposure action value set by the Health and Safety Executive, UK. Their study included an anesthetist and product specialist; the noise reading for both of them did not exceed the lower acceptable exposure values.[12]

In comparison between robotic systems, the study by Hönecke *et al*. examined noise exposure during TKA that was assisted by robotics. Three robotic surgical systems were included in their study: the MAKO robot (Stryker), the NAVIO robot, and the CORI robot (Smith and Nephew). Although the MAKO robot had the highest average sound level among the three robot systems, the NAVIO robot had the highest peak sound level. The conclusion was that robotic-assisted TKA is a risk factor for NIHL.[13] The results of our study are comparable to those of both studies.

The average noise level for a period of time (LAeq) produced by MAKO (89.5 dBA) is similar to that produced by the regular Stryker saw system 5 (88.9 dBA) in laboratory settings.[14] Noise measurements during conventional TKA vary in the literature. Compared to conventional TKA, the noise in robotic TKA usually exceeded an LAeq of 85 dBA. Goffin *et al*. noise measurement in conventional TKA reached 80 dBA.[12] This was also concluded in a study by Peters *et al*. where the noise level was below 85 dBA.[15]

For noise levels above 85dBA, the National Institute for Occupational Safety and Health (NIOSH) recommends wearing hearing protective equipment regardless of duration.[2] Consideration should be given to wearing hearing protection during the performance of TKA with the Mako robotic system or with traditional, non-robotic instrumentation and to regular audiometric testing of OR personnel. The evaluation of active noise-cancelling headphones was conducted by Stadler *et al*., and the average noise LAeq was 61.9 dBA. Communication during the procedure was a concern.[16]

In addition, there might be institutional implications associated with breaching SWA OHS standards. The lower exposure action limit set by CNWR 2005 by the UK government was set at 80 dBA.[17] The study shows that the aforementioned limit was exceeded by surgeons who perform at least 4 TKRs a day. In such cases where noise exposure exceeds the limit of 80 dBA, employers might be required to provide information and training about noise mitigation and hearing protection, but no such recommendations are followed in the majority of surgical theaters across the globe.

Limitations of the study

The limited number of measurements obtained in this study, along with the variability of noise levels and the high amount of background noise in the OR, may all affect the accuracy of estimation of both the noise levels generated by each individual activity or piece of equipment and the daily dosage of noise.

CONCLUSION

RSE used in the study produced the highest noise levels at an LAeq of 89.5 dBA on average. Although noise regulations were not breached, the noise levels created by equipment such as the Mako robot are significant and may warrant hearing protection as per NIOSH recommendations. With the cumulative exposure of orthopedic personnel to RSE and other orthopedic equipment, the risk of NIHL will increase over many working years, particularly when multiple surgeries are performed daily. This study estimates that the LEX 8h was nearing the regulation limit with as few as two TKAs daily. At 4 TKAs in a single day, the CNWR 2005 lower action limit (80 dBA) would be exceeded, requiring the employer to provide information about noise, training, and hearing protection.

Caution must be taken to mitigate the potential effects of long-term exposure to excessively high noise levels produced by RSE, such as the Mako robot, and OR personnel exposure to occupational noise should be further investigated. Testing the impact of long-term noise exposure on the hearing of OR personnel is worth considering, possibly through audiometric testing of subjects who are at risk. Improving the awareness of the damaging effects of noise and developing both administrative and engineering controls, such as wearing hearing protective equipment, will provide positive steps toward mitigating the effects of occupational noise in the OR.

Authors' contributions: SJM, WKC, and GMH: Conceived and designed the study and conducted literature searches and experimental studies. MM, MA, and WKC: Contributed to data analysis, statistical analysis, and data acquisition. CJW and MAA: Contributed to manuscript preparation, conduct literature search, and wrote the final draft. SJM, MM, and GMH: Wrote the initial and final drafts of the article. All authors have critically reviewed and approved the final draft and are responsible for the manuscript's content and similarity index.

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Declaration of participant consent: The authors certify that they have obtained all appropriate participant consent forms. In the form, the participants have given their consent for their images and other clinical information to be reported in the journal. The participants understand that their names and initials will not be published, and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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