Abstract

Pregnant or lactating staff working in the orthopaedic operating room may be at risk of occupational exposure to several hazards, including blood-borne pathogens, anesthetic gases, methylmethacrylate, physical stress, and radiation. Because the use of proper personal protective equipment is mandatory, the risk of contamination with blood-borne pathogens such as hepatitis B, hepatitis C, and HIV is low. Moreover, effective postexposure prophylactic regimens are available for hepatitis B and HIV. In the 1960s, concerns were raised about occupational exposure to harmful chemicals in the operating room such as anesthetic gases and methylmethacrylate. Guidelines on safe levels of exposure to these chemicals and the use of personal protective equipment have helped to minimize the risks to pregnant or lactating staff. Short periods of moderate physical activity are beneficial for pregnant women, but prolonged strenuous activity can lead to increased pregnancy complications. The risk of prenatal radiation exposure during orthopaedic procedures is of concern, as well. However, proper lead protection and contamination control can minimize the risk of occupational exposure to radiation.

The demographics of the orthopaedic operating room (OR) are changing. The number of female technicians, physician assistants, medical students, residents, and orthopaedic surgeons working in the OR has increased. Sixty-one percent of practicing physician assistants are women. In 1982 to 1983, 26.8% of medical school students were women. The number of female orthopaedic surgery residents has increased from 0.6% in 1970 to 13% in 2008. At our institution, 82.4% of the OR staff is female, and of those, four to five pregnancies are reported annually.

As the number of women working in the orthopaedic OR increases, the number of pregnant and lactating staff in the orthopaedic OR will also increase. Complications associated with perinatal exposure to occupational hazards in the OR are of primary concern. These complications include preterm labor and delivery, spontaneous abortion, fetal anomalies, mental retardation, and intrauterine growth restriction. Here, we examine the potential occupational hazards present in the orthopaedic OR, including blood-borne pathogens, anesthetic gases, methylmethacrylate (MMA), physical stress, and radiation, and the risks that they pose to pregnant and lactating OR staff.

Blood-borne Pathogens

Orthopaedic surgeons have an increased rate of occupational exposure to blood-borne pathogens related to...
their work with sharp instruments, metal objects, bone fragments, and power tools. Wong and Leung found that the primary methods of exposure to these pathogens were percutaneous and mucocutaneous. In the literature, the reported rates of percutaneous injury during orthopaedic surgery range from 1.7% to 15%. However, mucocutaneous exposure has increased in the orthopaedic OR secondary to face and neck contamination via blood spatter associated with the use of power tools and irrigation. Exposure to blood-borne pathogens has been reported to be as high as 50%. The hepatitis B and C viruses and HIV are the main blood-borne pathogens to which orthopaedic surgeons are exposed. The overall risk of exposure is low for pregnant and lactating OR staff secondary to the mandatory use of personal protective equipment, but the risk still exists. The use of personal protective equipment is crucial for preventing exposure to these pathogens. Double gloving is more effective than single gloving for reducing the risk of percutaneous exposure. However, the use of glove liners or cloth outer gloves has been shown to be more effective than double gloving in reducing exposure to blood-borne pathogens. Full facial coverage is required to decrease the risk of mucocutaneous exposure resulting from the use of power tools and pulsed irrigation.

**Hepatitis B**

Several studies have reported that the risk of transmission of hepatitis B via a single percutaneous exposure to infected blood from an unvaccinated person ranges from 6% to 30% (Table 1). The risk of transmission associated with mucocutaneous exposure to the virus has not yet been quantified. However, in the event of exposure, effective prophylactic protocols are available, including the hepatitis B vaccine, with or without immunoglobulin. The vaccination and immunoglobulin may be administered at any time during pregnancy without risk of adverse fetal outcomes.

Maternal-fetal transmission of hepatitis B typically occurs at the time of delivery. The rate of vertical transmission from mother to infant depends on the status of the mother's infection. If the mother is seropositive for both hepatitis B surface antigen and e-antigen, the rate of transmission to the fetus is 90%. If the virus is not actively replicating, but infection is present (as demonstrated by seropositive markers for hepatitis B surface antigen, anti-hepatitis B surface antibody, and negative hepatitis B DNA), the risk of transmission ranges from 10% to 30%.

The timing of maternal infection also affects transmission. If the mother is infected in the first trimester, there is a 10% chance that the neonate will test positive for hepatitis B. However, if infection occurs in the third trimester, the neonate's risk of infection increases to 80% to 90%.

Hepatitis B infection is not associated with an increased rate of malformation, intrauterine growth retardation, spontaneous abortion, or stillbirth. If the fetus tests seropositive for the hepatitis B e-antigen, the likelihood that chronic hepatitis B infection will develop is 85% to 90%. The prophylactic regimen for infants born to mothers with hepatitis B comprises a combination of both vaccination and immunoglobulin. This treatment interrupts vertical transmission in 85% to 90% of cases.

**Hepatitis C**

After percutaneous exposure to infected blood, the risk of hepatitis C transmission ranges from zero to 7%. Two cases of mucocutaneous transmission of hepatitis C have been reported in the literature; both cases were the result of conjunctival exposure. Unlike hepatitis B, a postexposure prophylactic regimen for hepatitis C is not yet available to prevent infection. Materno-fetal transmission of hepatitis C occurs through the placenta. If the virus is transmitted, the neonate is at risk for acute hepatitis, chronic hepatitis, or carrier status. No known teratogenic syndromes are associated with hepatitis C infection. At this time, no methods are available to prevent perinatal transmission of the virus.

**HIV**

The risk of HIV transmission through a single percutaneous exposure is low (0.3%), and the risk of transmission via mucocutaneous exposure is even lower (0.09%). After exposure, the standard prophylactic protocol includes azidothymidine plus lamivudine. Prophylaxis for pregnant and lactating healthcare professionals who are exposed to the virus requires more extensive consultation with infectious disease and obstetric specialists because of the potential risks of drug toxicity. In general, maternal-fetal transmission occurs late in pregnancy, at the time of delivery, or during breast-feeding. The vertical transmission rates are directly related to the HIV RNA load. With no treatment or breast-feeding, the maternal-fetal transmission rate ranges from 15% to 40%. Highly active antiretroviral therapy may reduce the vertical transmission rate to <2% if the maternal viral load can be reduced to <1,000 copies/mL.

**Anesthetic Gases**

Inhalation agents currently used in the OR include nitrous oxide and halogenated agents (eg, halothane, isoflurane, enflurane, sevoflurane, desflurane). Adverse effects associated with the use of these agents include an inhibitory effect on dividing cells and increased rates of abnormal cell division.
Table 1

<table>
<thead>
<tr>
<th>Disease</th>
<th>Risk of Transmission After Percutaneous Exposure (%)</th>
<th>Risk of Transmission After Mucocutaneous Exposure</th>
<th>Postexposure Prophylactic Regimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatitis B</td>
<td>6–30(^6,9)</td>
<td>NR</td>
<td>Hepatitis B vaccine with or without hepatitis B immunoglobulin</td>
</tr>
<tr>
<td>Hepatitis C</td>
<td>0–7(^10)</td>
<td>Two cases reported(^11,12)</td>
<td>None available</td>
</tr>
<tr>
<td>HIV</td>
<td>0.3(^5)</td>
<td>0.09(^4)</td>
<td>Azidothymidine and lamivudine</td>
</tr>
</tbody>
</table>

NR = not reported

formation and chromosomal abnormalities.\(^{14}\) The Occupational Safety and Health Administration of the US Department of Labor has established guidelines on permissible levels of anesthetic gas in the OR.\(^{18}\) According to these guidelines, the level of nitrous oxide should be limited to 25 ppm during the period of anesthetic administration. For halogenated agents, exposure should be limited to <2 ppm over a 1-hour period. Gas leaks can result in levels that exceed these guidelines. Potential sources of leaks include defective tank valves, tubing, and reservoir bags as well as improper anesthetic technique, such as leaving tank valves open, spilling the liquid form of the agent during canister exchanges, and poorly fitted face masks.\(^{14}\)

Exposure to waste levels of anesthetic gases, or the amount of anesthetic gas in the ambient air in anesthetizing locations, may have adverse effects on reproductive outcomes and has been a concern since the 1960s.\(^{19}\) Several early animal and epidemiologic studies published on the subject suggested that there was an increased risk of miscarriage and fetal congenital anomalies in women exposed to waste levels of anesthetic gas.\(^{20–22}\) However, these studies were found to be of inferior quality, and a later study called the results into question.\(^{23}\)

In a study of infertility among female physicians in England, female medical school graduates aged ≤40 years were surveyed.\(^{24}\) The authors found no significant relationship between increased infertility in female anesthesiologists or incidents of spontaneous abortion or congenital anomalies associated with maternal occupation, hours in the OR, or the use of salvaging equipment. These findings and the lack of high-quality evidence indicating an increased risk of adverse effects on reproductive health or pregnancy suggest that exposure to waste levels of these agents does not pose a risk for adverse reproductive outcomes.

**Methylnitrate**

MMA is a colorless, flammable liquid that has an acrid odor. It is metabolized to methacrylic acid, which is toxic to various tissues.\(^{25}\) Because of this toxicity, the US Environmental Protection Agency has set the permissible limit for occupational exposure to 100 ppm in the air over an 8-hour period. The acute toxicity of MMA, which manifests as irritation of the skin, eyes, or mucous membranes and generally occurs with exposure to MMA at 1,000 ppm, has been investigated.\(^{25}\)

Similar to anesthetic gases, concern regarding occupational exposure to MMA and associated adverse effects on pregnancy outcomes began in the 1960s as a result of findings from several animal studies that showed that MMA had teratogenic effects in rodents.\(^{26–29}\) MMA can be fetotoxic at levels >1,000 ppm. The potential toxic effects may result in growth retardation, skeletal malformations, and increased fetal resorption.

Several studies have examined the levels of exposure to MMA in the orthopaedic OR. The first study measured the concentration of MMA monomer at four intervals during a total hip arthroplasty.\(^{27}\) The maximum concentration of MMA in the air was 280 ppm. Other studies have quantified the levels of exposure for nurses, scrub technicians, and surgeons working in modern OR conditions.\(^{30,31}\) The surgeon received the highest level of exposure (100 ppm) during total joint arthroplasty. The maximum exposure level recorded during vacuum bone cement mixing was 4 ppm; hand mixing resulted in higher levels of exposure (17 ppm).\(^{31}\) Personal protective helmet systems and local punctual field suction can minimize exposure to MMA.

Linehan and Gioe\(^{32}\) measured levels of MMA in serum and breast milk following exposure to MMA during arthroplasty. No helmet systems were used during the procedure. Serum and breast milk from two lactating surgeons were tested and compared with controls. The authors reported that the serum and breast milk samples showed no evidence of MMA, and the surgeons’ samples did not test higher than those of the controls. Currently, personal helmet systems are not a required part of protective equipment for pregnant or lactating
women working in the OR; however, the use of these systems can lower exposure to MMA.\textsuperscript{30} Because the risk of exposure to high levels of MMA in the OR is minimal, the potential risk of adverse effects in pregnant and lactating staff in the orthopaedic OR is low.

**Physical Stress**

Orthopaedics is a physically demanding occupation that requires prolonged periods of standing and heavy lifting. Lerner and Ro\textsuperscript{33} measured the physical work done by four orthopaedic surgeons during various surgical procedures and found that the mean aerobic work was 20% to 30% of the surgeons' maximum aerobic capacity. For female orthopaedic surgeons, the level of activity during pregnancy may be of particular concern.

In general, exercise during pregnancy has a substantial number of psychological and physical benefits, including improved self-esteem, decreased rates of depression, and decreased fatigue.\textsuperscript{34} Exercise has been found to improve several conditions associated with pregnancy such as varicosities, peripheral edema, and high blood pressure in addition to improved response to carbohydrates and decreased blood glucose. The American Congress of Obstetricians and Gynecologists (ACOG) recommends moderate exercise for \( \geq 30 \) minutes on most days of the week for women with uncomplicated pregnancies.\textsuperscript{35}

Extrapolating the data on exercise and pregnancy to fit an occupational context is problematic because occupational activity can be more physically demanding than moderate exercise and may require prolonged hours. This is especially relevant to orthopaedic surgery. Several studies of the general population have shown that, during pregnancy, prolonged standing (\( > 8 \) hours per day) and long working hours (\( > 40 \) hours per week) may increase the risk of preterm birth and may negatively influence intrauterine growth.\textsuperscript{36-38} The negative effect on intrauterine growth was found to be comparable to that of maternal cigarette smoking.\textsuperscript{36,38}

Two studies have evaluated the effects of physical stress on pregnancy in a physician population.\textsuperscript{39,40} Klebanoff et al\textsuperscript{39} compared pregnancy outcomes in female residents (group I) with those of the wives of their male medical school colleagues (group II). The authors noted that preclampsia and preterm labor were more common in group I than in group II. Furthermore, analysis of a subset of female residents who worked \( > 100 \) hours per week showed an increased rate of preterm birth in the third trimester compared with those who worked \( < 100 \) hours (10.3% versus 4.8%). The second study focused on pregnancy outcomes in female orthopaedic surgeons.\textsuperscript{40} The authors found that, compared with the general population, female orthopaedic surgeons had an increased risk of complications during pregnancy, with preterm labor and delivery being the most common complications. This increased risk was found to be prevalent in those who worked \( > 60 \) hours per week.

The current literature does not explain why increased occupational activity can lead to adverse pregnancy outcomes.\textsuperscript{41} Studies on the characteristics of occupational activity during pregnancy have yielded conflicting results.\textsuperscript{36-38} With regard to the occupational demands of orthopaedic surgery, possible causes of adverse pregnancy outcomes include the combination of prolonged standing and demanding physical activity (eg, bending, squatting, heavy lifting), which can decrease uterine blood flow and increase intra-abdominal pressure.

Prolonged daily work hours and stressful work conditions can lead to fatigue and dehydration, which are risk factors for preterm labor. Orthopaedic surgeons also have a tendency to decrease water intake when in the OR. Additionally, insensible water loss associated with the use of lead personal protective equipment and the heat of the OR lights may contribute to dehydration. Dehydration in lactating women can lead to mastitis and obstructed lactational ducts, which may become significant health issues.

The lactating orthopaedic surgeon must pump breast milk frequently throughout the day, typically every 4 hours. This requirement can create an issue for trainees in particular because they may have few breaks and little control over their schedules and may work long hours. Failure of scheduled pumping can lead to blocked lactational ducts and mastalgia.

Submaximal physical activity (<70% of maximum aerobic capacity) performed for short periods on most days of the week is beneficial for pregnant and lactating women who work in the OR.\textsuperscript{34} Although strenuous activity has been associated with adverse pregnancy outcomes, orthopaedic surgeons expend only 20% to 30% of maximum aerobic capacity during surgery;\textsuperscript{33} thus, the occupational risk of adverse effects associated with strenuous activity is low.

**Radiation**

Guidelines for exposure to ionizing radiation in pregnant patients and healthcare professionals vary widely among regulatory agencies and professional societies. Both the American College of Radiology and the ACOG have developed guidelines on radiation exposure during radiographic imaging of pregnant or lactating patients.\textsuperscript{42,43} These guidelines discuss the risks and benefits of diagnostic radiation in this patient population. Both the American College of Radiology Resolution No. 48 and the ACOG Committee Opinion No. 299 state that exposure of <5 rads (50 mSv or 50 mGy) is not
harmful to the fetus. These guidelines could be applied when counseling pregnant or lactating healthcare professionals after accidental exposure to radiation in the workplace.

The effects of radiation exposure on the fetus depend on the amount of radiation received and the gestational age of the fetus at the time of exposure. Adverse effects are most significant during organogenesis (weeks 3 to 8 of gestation) and decrease throughout the remainder of the pregnancy. The effects of radiation exposure are the result of cell death or damage to DNA. Cell death associated with prenatal exposure to ionizing radiation can result in intrauterine lethality and malformation of organs and the central nervous system. Exposure to high doses of radiation at an early gestational age can result in spontaneous abortion. At preimplantation (weeks 0 to 2 of gestation), exposure to a radiation dose of 100 to 150 mGy (the equivalent of more than three pelvic CT scans) may have lethal effects. At term, exposure resulting in lethal effects increases to 1,000 mGy. Exposure to a radiation dose of 50 to 500 mGy at 3 to 8 weeks of gestation can result in organ malformation. The neurologic, urinary, and skeletal systems are most susceptible to organ malformation. Abnormalities of the central nervous system are another important deterministic effect of radiation. Several central nervous system disorders are related to radiation exposure in excess of 100 mGy, including severe mental retardation, cognitive impairment, and seizure disorders.

The effects of radiation-induced damage to DNA (eg, leukemia, solid cancers) are cumulative. The risk of developing cancer secondary to in utero exposure to radiation increases with repeated exposure and is independent of a minimum threshold. In a study of data from the Oxford Survey, children who received prenatal exposure to radiation had a relative risk of 1.47 of developing childhood cancer; however, the prenatal radiation dose was not recorded. Because the incidence of childhood cancer is only 0.2% to 0.3%, the overall risk of cancer associated with exposure to a 10-mGy dose of radiation would still be very low (0.3% to 0.4%). Several studies have documented a relationship between prenatal radiation exposure and thyroid cancer. A literature review on the effects of prenatal exposure to ionizing radiation reported a significant increase in pediatric thyroid cancer <5 years after prenatal exposure during the second and third trimesters.

Estimates of the risk of radiation exposure for pregnant and lactating women working in the orthopaedic OR require an assessment of the level of radiation present during orthopaedic procedures. Uzoigwe and Middleton measured the level of radiation that the surgeon's abdomen is exposed to when a standard 0.25-mm single lead apron is worn during several common orthopaedic procedures. These values were then used to calculate the fetal radiation dose per procedure. In a tibial nailing procedure, the fetal dose was 0.014 mGy. Femoral nailing, which has a much higher level of radiation exposure, resulted in a fetal radiation dose of 0.044 mGy per procedure.

At our institution, the level of radiation to which orthopaedic residents were exposed over a 1-month period was measured. Forty residents wore dosimeters during every OR procedure. One dosimeter was worn at the waist under standard lead protection. The second was worn at the level of the neck outside lead protection. Unlike Uzoigwe and Middleton, we found that the dosimeter worn underneath the standard lead apron demonstrated no exposure to radiation. This suggests that abdominal exposure to radiation can be eliminated when appropriate shielding is used.

Several strategies can be used to reduce radiation exposure in the OR, including increasing the distance from the source of radiation, reducing exposure time, using protective shields, and controlling radiation contamination. With regard to protective shielding, the International Commission on Radiological Protection (ICRP) and the Ionising Radiations Regulations mandate that a lead apron be worn by those with occupational exposure to radiation. A standard 0.25-mm lead apron will absorb 96% of the radiation for the mean range of voltage used during fluoroscopy. A double apron has a layer of lead that is 0.5 mm thick and absorbs 99% of radiation. The maternity apron has a layer of lead that is 0.5 to 1 mm thick. Although this would absorb over 99% of the radiation, it is very heavy. An apron with a 0.5-mm layer of lead is 1.5 times the weight of a standard 0.25 mm lead shield, and the apron with a 1-mm layer of lead is twice the weight of the standard lead apron. The ICRP recommends that exposure to radiation be limited to <1 mGy per the course of the pregnancy. This limit is far less than the single exposure to >5 rads (50 mGy) that can result in harm to the fetus.

The ICRP recommendations specifically address the risk of occupational exposure to radiation rather than exposure to medically guided diagnostic radiation in pregnant patients. Radiation exposure can be minimized with the use of lead aprons, contamination control, and the proper use of a dosimeter in the OR. It is important to note that double lead aprons have added physical stress and ergonomic implications for the pregnant orthopaedic surgeon.

Summary

Pregnant and lactating women who work in the orthopaedic OR are exposed to several potential occupational hazards, including blood-borne pathogens, harmful chemicals, physical...
stress, and radiation. Because of concern regarding potential infection associated with exposure to bloodborne pathogens, the use of personal protective equipment is critical. Double gloving has been found to be more effective than single gloving for preventing exposure to these pathogens, and the use of glove liners or cloth outer gloves is superior to double gloving. Face and neck protection is also crucial to protect against mucocutaneous exposure to these pathogens.

In terms of occupational exposure to harmful chemicals in the OR, anesthetic gases pose minimal risk to the pregnant and lactating women who work in the orthopaedic OR based on the findings from epidemiologic studies. In addition, MMA was not found to be a significant hazard to this population when the proper protective precautions are used. The use of a vacuum mixer and personal hood protectant system can eliminate exposure to MMA.

Physical stress remains an area of concern for pregnant orthopaedic surgeons. Prolonged standing, demanding physical activity, and long work hours may lead to increased complications such as preterm labor, preeclampsia, or intrauterine growth retardation. In lactating women, intense physical activity without frequent breaks can result in dehydration, mastitis, obstructed lactational ducts, and mastalgia.

Occupational exposure to radiation in the orthopaedic OR is another cause for concern for the pregnant healthcare professional. However, the use of preventive strategies, including proper lead protection, contamination control, and the use of dosimeters, can minimize the risk of exposing the fetus to a harmful level of radiation.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 27, 28, and 38 are level II studies. References 23, 24, and 39 are level III studies.

References printed in bold type are those published within the past 5 years.


23. Axelsson G, Rylander R: Exposure to anesthetic gases and spontaneous


