Abstract: The number of female orthopaedic residents and orthopaedic surgeons has increased substantially. Concerns have been raised regarding the effect of the work environment on the health of the female orthopaedic surgeon and her fetus or neonate. Occupational risks, and specifically risks to the pregnant orthopaedic surgeon, are becoming an important issue in medicine. Such risks include exposure to methylmethacrylate (MMA), anesthetic gases, blood-borne pathogens, radiation, emotional stress, and physical stress. Awareness of and knowledge about such exposures are needed for the pregnant orthopaedic surgeon to make informed decisions about her occupational exposures and to be proactive about her own and her child’s health.

The percentage of women in medical schools in the U.S. increased from 11.1% in 1970 to 48.3% in 2007, and the percentage of women in orthopaedic residency training programs increased from 0.60% in 1970 to 12.0% in 2009. According to Katz et al., the rates of preterm labor, preterm delivery, low birth weight, and abruptio placentae are higher in female physicians compared with the general female population. Although pregnancy complications can also result from other factors, such as having children later in life, complications during early pregnancy can be attributed to exposure to chemicals, gases, radiation, and infectious diseases.

This paper will review the occupational hazards associated with orthopaedic surgery. The hazards associated with methylmethacrylate (MMA), anesthetic gases, blood-borne pathogens, radiation, emotional stress, and physical stress are of specific concern for the pregnant orthopaedic surgeon. Because female orthopaedic surgeons are consistently exposed to these risks, a review and discussion of the available literature will be presented to allow the practicing female surgeon to make informed decisions about her prenatal and postnatal exposures.

Potential Occupational Hazards
Methylmethacrylate (MMA)
Methylmethacrylate (MMA) is commonly used as the cement for fixation of orthopaedic prosthetic devices. The U.S. Environmental Protection Agency recommends exposure to a time-weighted average of no more than 100 parts per million (ppm) of MMA over an eight-hour work day.

Developmental effects following MMA exposure have been documented in animal studies. Singh et al. calculated the acute toxicity and lethal dose of MMA in rats to be approximately...
1.33 mL/kg. On the basis of these calculations, pregnant rats received an intraperitoneal injection of MMA at one-tenth, one-fifth, or one-third of the acute lethal dose. Dose-related increases in gross and skeletal abnormalities of the fetus and a reduction in fetal weight at birth were observed7. A similar study by McLaughlin et al. evaluated the effect of MMA vapor on pregnant mice8. The MMA exposure was markedly greater than the recommended occupational exposure (1330 ppm compared with 100 ppm averaged over an eight-hour day). However, the proportion of normal compared with abnormal fetuses and the number of fetal deaths did not differ significantly compared with unexposed mice9. McLaughlin et al. also studied the MMA concentration that resulted from MMA mixing. MMA exposure was greatest in the operating room during the beginning of the mixing process, going from 280 ppm to < 10 ppm eleven minutes after the start of mixing. Although these two studies are over thirty years old, to our knowledge no current studies have examined the lethal dose or toxicity of MMA in pregnant animals.

Schlegel et al. compared various vacuum mixing devices to classic hand mixing of MMA in an open bowl10; gas chromatography was used to measure the concentration of MMA at the level of the nurse’s breathing zone during the mixing procedure. Use of the vacuum mixing devices resulted in a substantial reduction of 50% to 75% in the concentration of MMA vapor in the breathing zone. However, the characteristic smell of MMA, which can be detected at a concentration as low as 0.2 ppm, was still evident11. Darre et al. measured an MMA concentration of 50 to 100 ppm in the breathing zone of a surgeon performing hip arthroplasty; however, use of a surgical helmet or local surgical field suction reduced this to an undetectable level12. In a similar study, Cloft et al. measured the concentration of MMA vapor during percutaneous vertebroplasty13. The cement was mixed without the use of a fume hood or vapor control device. The room air flow was 22 air changes per hour. The concentration of MMA vapor in air samples taken from the location of the surgeons was less than the study’s detection limit of approximately 5 ppm. Thus, Cloft et al. concluded that a fume hood was not necessary for MMA use during vertebroplasty13.

Finally, a study conducted by Linehan and Gioe investigated the effect of MMA exposure on breast milk14. The authors measured the MMA concentration in the serum and breast milk of orthopaedic surgeons after they had performed hybrid total hip and total knee arthroplasty15. No evidence of MMA was found at the 0.50 ppm level, and no surgeon’s samples tested higher than the control specimens did. Even though the study by Linehan and Gioe included only surgeons who used vacuum mixing and a vertical laminar flow hood, other modalities such as surgical helmets, local surgical field suction, vapor control devices, or room air exchange could presumably also reduce the MMA concentration in the serum and breast milk of orthopaedic surgeons to an undetectable level16.

**Anesthetic Gases**

Exposure to anesthetic gases also poses a risk for the pregnant orthopaedic surgeon because such agents potentially have an inhibitory effect on dividing cells. Exposure to these agents can increase the rate of formation of abnormal cells and the rate of chromosomal aberrations; however, this has not been demonstrated at doses used for general anesthesia17. Moreover, sub-anesthetic levels have not exhibited fetotoxic effects18.

The Occupational Safety and Health Administration of the U.S. Department of Labor provides guidelines to advise and assist employers in providing and maintaining a healthy work environment19. Regulations for hospitals limit the permissible level of anesthetic gases in the air of the operating room, with the limit for nitrous oxide being a time-weighted average of 25 ppm over the period of anesthetic administration and the limit for halogenated agents being 2 ppm averaged over a one-hour period20. However, leaks do occur, with the potential sources being tank valves, tubing defects, and reservoir bags21. Improper anesthesia techniques and improper practices (such as leaving valves open, spilling anesthetic agents, or inadequately fitting face masks) can also contribute to exposure. Although efforts to control anesthetic gas pollution have led to substantial improvements over the years, occupational exposure still occurs22.

**Blood-Borne Pathogens**

Exposure to blood-borne pathogens is another potentially serious occupational risk to pregnant female orthopaedic surgeons, who frequently handle sharp instruments, metal objects, and bone fragments during surgery23. The blood-borne pathogens that are most commonly involved in occupational transmission are hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV)24,25. Exposure to anesthetic gases also poses a risk for the pregnant surgeon because of its potential fetal health consequences to the fetus if the mother goes untreated. Azidothymidine (AZT) is commonly used in post-exposure prophylaxis, as it is the only drug that has been shown to reduce the risk of HIV infection26. Connor et al. conducted a multicenter trial in which AZT administration to HIV-infected pregnant women was associated with a 67% reduction in the transmission of HIV to the fetus27.

Limited information on the side effects of antiretroviral drugs on the developing fetus or neonate is available28. However, in vitro screening tests have suggested that AZT and all other nucleoside reverse transcriptase inhibitors (NRTIs) licensed by the Food and Drug Administration (FDA) may be carcinogenic and/or mutagenic29. Moreover, there is a risk of transmitting HIV, nucleoside reverse transcriptase inhibitors, and the protease inhibitor nelfinavir to the infant via breast milk, and it is not known whether other approved antiretroviral drugs also pass through breast milk30. Thus, women who experience a high-risk exposure should consider discontinuing breast feeding. According to the World Health Organization (WHO), breastfeeding is recommended except if the mother either has HIV or has been exposed to HIV and is unsure whether she has become infected. In this instance, even if the mother is being treated with antiretroviral drugs, the WHO...
recommends that she avoid breastfeeding and find a replacement feeding that is sustainable and safe.

Radiation
Orthopaedic surgeons rely heavily on the use of radiography, including intraoperative fluoroscopic imaging. This use of radiography has the potential to expose the pregnant female surgeon and her fetus to dangerously high levels of radiation. Most of the available data on the effects of radiation on the human body, including on the fetus, were obtained by studying the 1945 atomic bomb survivors from Hiroshima and Nagasaki. This group included approximately 2800 pregnant women, 500 of whom received a radiation dose of >500 to 1000 milliGray (mGy).

According to the National Council on Radiation Protection and Measurements (NCRP), the maximum radiation exposure to the fetus before harm occurs is 0.05 Gy. Potential side effects of radiation exposure of >0.05 Gy to the fetus include prenatal death, growth restriction, small head size, severe mental retardation, organ malformation, and childhood cancer. These side effects depend on the radiation dose and on the developmental stage of the conceptus at the time of exposure. Because the embryo or fetus is more sensitive to radiation at certain stages of development, radiation risks decrease as the pregnancy progresses. Prior to two weeks of gestation, the embryo is very sensitive to radiation, and a dose of >0.1 Gy (equivalent to approximately 75 fluoroscopy uses or extremity radiographs) may cause death of the embryo. However, if the embryo survives, radiation-induced non-cancer health effects are uncommon. As long as the fetal dose remains <0.05 Gy (equivalent to approximately 38 fluoroscopy uses or extremity radiographs) throughout the duration of the gestation, radiation-induced non-cancer health effects are usually not detectable.

The International Commission on Radiological Protection (ICRP) has estimated the risk of cancer during childhood and the lifetime cancer risk associated with prenatal radiation exposure. According to the ICRP, a prenatal exposure of <0.05 Gy is associated with an estimated 0.30% to 1.00% rate of childhood cancer and an estimated 38% to 40% lifetime cancer rate, rates which are similar to those associated with no prenatal radiation exposure. An exposure of >0.50 Gy is associated with a >6% childhood cancer rate and a >55% lifetime cancer rate.

Thus, diagnostic radiation doses are associated with a small risk of cancer, but no evidence for an increase in mental retardation, congenital malformations, or microcephaly has been shown to be associated with the occupational exposure that a pregnant orthopaedic surgeon’s child would typically receive over the course of the pregnancy. Most radiology exposures without protection to the pregnant orthopaedic surgeon’s child result in fetal absorption of <0.05 Gy per exposure.

In order to reduce their exposure during radiography, the NCRP recommends that personnel should work at least 2 m away from the radiation source. A recent study by Shaw et al. noted that a pregnant physician can reduce the radiation exposure of the fetus by a factor of four by doubling her distance from the radiation source. Furthermore, the NCRP reported that a standard 0.5-mm-thick lead apron attenuates 99% of radiation. Other reports have recommended that radiation monitors be worn at collar level outside the lead apron and at the fetal level inside the apron. Maternal tissues will attenuate 70% of the remaining radiation that is not absorbed by the apron, so only 30% will reach the fetus. A fetal lead apron, which has 0.5 mm of lead only at the fetal level, is also available. According to Marx et al., the use of a fetal lead apron, in conjunction with the standard lead apron, reduces radiation exposure to the fetus by an additional 66%. Thus, it is recommended that a pregnant orthopaedic surgeon wear two lead aprons, standard and fetal, in order to reduce radiation exposure to both herself and her fetus.

Stress
Both emotional stress and physical stress pose an occupational hazard to the female orthopaedic surgeon.

Emotional Stress
Potential emotional stressors for any female surgeon include discrimination, lack of role models, role strain, and overload. These stressors can lead to depression, suicide, and divorce, with the rates of suicide and divorce being greater among female surgeons than among the general female public.

There are conflicting views on the effects of stressors involving family life on female physicians. On the one hand, women physicians often lack mentors to provide guidance on issues such as the most appropriate time to have a child and the way to handle conflicts between professional, personal, and family lives. Conversely, another study has shown that family life can actually decrease a surgeon’s emotional stress level. The Physician Worklife Study, which examined career satisfaction and various aspects of work life among physicians, showed that work-family conflicts may not be a source of burnout in female physicians. Also, although female surgeons were more likely to be childless, those with at least three children were happier and more emotionally stable than those with one or no children.

According to a 1992 study by Phelan, 31% of 1197 female residents experienced pregnancy during residency. The residents cited fatigue from being on call and working extended hours, limited time with a spouse or partner, and increased physical activity and emotional strain as causes of stress. This psychological stress can have a negative effect on the fetus, such as preterm birth and lower birth weight.

A more recent survey of forty-two surgical residency graduates by Mayer et al. in 2001 found that fourteen of the twenty-two men and three of the twenty women had children born during residency. Mayer et al. found that 80% of these seventeen residents would have considered practicing surgery part time in exchange for more time with their children. Moreover, the 1999 report of the American College of Surgeons’ Advisory Council for General Surgery brought to light the fact that surgery training programs fail to confront social and professional issues regarding pregnant residents. Thus, even with the stricter work hour restrictions that are now in place for residents, there is still an emotional struggle, and additional stress, for orthopaedic residents who want to have a family.
Physical Stress

The specialty of orthopaedic surgery inherently involves a level of physical exertion greater than that seen in many other medical or surgical subspecialties. Furthermore, the demands of on-call trauma treatment can be associated with long hours of standing, lifting, and bending. These occupational factors may be of special concern for the pregnant orthopaedic surgeon because of the potential for work-related musculoskeletal complaints to magnify during pregnancy. The musculoskeletal changes during pregnancy are predominantly related to alteration of the center of gravity, weight gain, the effect of circulating hormones on ligaments, and fluid retention. Low back pain occurs in as many as one-half of all pregnant women.44 As a pregnant woman assumes a position of hyperlordosis, this shift in load distribution theoretically generates increased stress on the intervertebral discs, facet joints, and ligaments.45

Adjusting occupational conditions for working pregnant women to result in shorter work hours, more frequent sitting, and improved body posture when sitting has been advocated to ameliorate low back pain.46 In order to better incorporate these recommendations into her daily life, a pregnant full-time orthopaedic surgeon should be educated regarding these modifications and should be proactive in implementing these preventive measures, starting in the first trimester.47-49

Summary

Although male and female surgeons face similar occupational risks in the work environment, the effects of these risks on a pregnant orthopaedic surgeon’s fetus or neonate make her situation unique. Whether it is exposure to MMA, anesthetic gases, blood-borne pathogens, radiation, or stress, the female orthopaedic surgeon should know about how her occupational risks prior to, during, and following pregnancy might affect not only her health but her child’s health.

The number of female orthopaedic residents has increased 33% from 2001 to 2008. As the number of female surgeons continues to increase, improved awareness of the unique occupational risks to pregnant orthopaedic surgeons—and a proactive approach to prevent or minimize such risks—are imperative for the well-being of the mother and her child.

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