Occupational Hazards Facing Orthopedic Surgeons

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Abstract

Physicians are exposed to occupational hazards of which they are often unaware. Orthopedic surgery has a particularly hazardous work environment in which surgeons are at increased risk for exposure to infection, radiation, smoke, chemicals, excessive noise, musculoskeletal injuries, as well as emotional and psychological disturbances. Understanding these risks and the precautions that can be taken to avoid them will help protect orthopedic surgeons from potential harm.

Most physicians are often unaware of the risks posed by the occupational hazards in their daily work environment. This is particularly true in orthopedic surgery, a field that exposes surgeons to an array of potentially dangerous agents and, at the same time, places them under enormous physical and emotional strain. It is important for orthopedic surgeons to be aware of not only the potential hazards they face in the operating room, but also of the precautions that can be taken to avoid any problems. In this article, we review these hazards and current safety recommendations to better prepare surgeons for the risks of the operating room.

Exposure to Infection

Surgeons have a known elevated risk for exposure to blood-borne pathogens because of the elevated rate of percutaneous injuries. These injuries typically occur accidentally while suturing or passing the needle.[1-3] For orthopedic surgeons, the risk is even higher because of their increased contact with sharp instruments and objects, including power saws, drills, Kirschner wires, and the handling of sharp bone fragments. This is evidenced by the higher exposure rate in orthopedic trauma procedures.[4] The pathogens most often investigated are human immunodeficiency virus (HIV), hepatitis B virus (HBV), and hepatitis C virus (HCV) (Table I). The estimated risks for HIV, HBV, and HCV infection through percutaneous injury are 0.3%, 6% to 30%, and 1.8%, respectively.[5,6] In cases where sharps are placed on a neutral zone, use of a hands-free technique is recommended to avoid injury.[7,8]

In addition, splattering from irrigation and power tool use increase orthopedic surgeons' mucocutaneous exposure to blood-borne pathogens.[9] Through mucocutaneous exposure, the risk for HIV infection is 0.09%; the risk for HBV infection has not been quantified but is thought to be higher than that of other blood-borne pathogens; and while the risk for HCV infection is rare, cases have been reported.[5,6,10-12]

The risk for HIV infection decreases 81% with postexposure prophylactic use of zidovudine; other antivirals may also decrease infection, however, this has not been studied. It is important to note that the risk for infection, even without prophylaxis, is quite low and that zidovudine has numerous side effects.[13-15] The HBV vaccine is effective and postexposure prophylaxis with hepatitis B immunoglobulin may have an added benefit for those patients not vaccinated.[10] No vaccines or medications have been found to be effective as postexposure treatment for preventing HCV infection.[15] These infection risks depend on a variety of factors including type of pathogen, infectivity of pathogen in blood of patient at time of exposure, type and severity of injury, and use of pre-exposure and postexposure treatments.[16]

The Hospital Infection Control Practices Advisory Committee developed standard precautions for preventing exposure to pathogens.[17] The basis of these guidelines is to consider all patients potentially infectious, and therefore, take all necessary precautions, including frequent hand washing, use of gloves, gowns, masks, and eye protection.[17] Hand washing reduces not only the incidence of nosocomial infections, but also the acquisition of hospital pathogens by hospital personnel.[18]

A review of multiple studies on glove use concluded that wearing a double layer of latex gloves significantly decreased the rate of exposure, compared with wearing a single layer of latex gloves. Wearing cut-resistant gloves and changing outer gloves at a predetermined interval further reduced the exposure rate.[19-21] Results of a study by Watts and colleagues[22] confirmed a significant difference in sensation between single and double gloves with similar pressure applied, but ultimately, surgeons must use what they prefer.

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In orthopedic surgery, face mask and eyewear are particularly important in preventing the mucocutaneous exposure and eye trauma that can be caused by the spray of blood and bone fragments that occur with frequent use of power tools. Mansour and colleagues[23] found that the most protection against conjunctival contamination was provided by disposable plastic glasses, followed by hard plastic glasses, combined facemask and shield, and surgical loupes; modern prescription glasses were of no benefit.

Surgical gowns further provide a barrier to exposure.[24] Gowns with higher water and oil repellence and smaller pore size provide the most protection.[24] Body exhaust suits can provide additional protection from droplet transmission, although additional respiratory protection is necessary only when there is an airborne transmission risk.[15]

Exposure to Radiation

Orthopedic surgeons use intraoperative imaging much more often than other surgical specialists, and thus, are at higher risk for radiation exposure. In addition, orthopedic surgeons must often remain near the x-ray beam and cannot distance themselves to reduce their exposure to radiation.[25]

The effects of radiation exposure fall into 2 categories—stochastic and nonstochastic. Stochastic effects are the result of chromosome damage. In somatic cells, they typically manifest as cancer; in germ cells, as genetic defects in offspring.[26-28] Severity is unrelated to radiation dose. However, higher doses increase the probability that stochastic effects will occur. In contrast, nonstochastic effects require a threshold dose. This dose differs between individuals and the magnitude of effects increases with higher doses. Nonstochastic effects typically present within hours or days of exposure and can include erythema, burns, sterility, radiation sickness, and even death; doses high enough to cause death are not typically encountered in the operating room.[29] If the threshold is not reached, cellular damage is repaired, and cumulative effects or long-term sequelae are prevented.[29]

The recommended dose limit has been revised downward multiple times since 1934. Currently, the US National Council on Radiation Protection and Measurements (NCRP) recommends a maximum annual total body dose of 5 rem and the International Commission on Radiological Protection recommends 2 rem.[26] For reference, a single chest x-ray delivers 0.03 rem of radiation. There are additional guidelines for maximum allowable doses specific to pregnant women, children, and specific organs (Table II).[26,27] Interestingly, maximum radiation exposure for the gonads does not differ from that for the torso, even with study results suggesting that too much radiation to the gonads may lead to infertility and birth defects, including anencephaly, spina bifida, congenital cataracts, small head circumference, and low birth weight.[25,30,31] Exposure to the gonads should nevertheless be kept to a minimum until a definitive study is conducted.

Most of the radiation orthopedic surgeons are exposed to is not primary radiation from x-ray beam, but scattered radiation. Exposure rates are 1200 to 4000 mrem/min for primary radiation from a standard C-arm and 5 mrem/min for scatter radiation 0.61 m (2 ft) from the beam;[25] doubling the distance from the source reduces the intensity by a factor of 4.[25,32]

Many investigators have studied exposure rates for different procedures. Noordeen and colleagues[33] calculated yearly exposure to the hands of 4740 mrem (approximately 10% of the yearly maximum dose for the hands) during studied orthopedic trauma procedures. Radiation exposure was approximately 10 times higher during spinal surgeries than during other musculoskeletal procedures. Rampersaud and colleagues[34] found that hand exposure rate was 58.2 mrem/min during pedicle screw fixation. Mroz and colleagues[35] found 5.7 minutes of exposure time for a single-level kyphoplasty. Exposure rates were highest when the C-arm was placed in the lateral position and was significantly reduced when the primary beam entered the patient opposite the surgeon, minimizing surgeon exposure to scattered radiation (Figure 1).[36,37]

Some have recommended the use of a mini C-arm over the standard C-arm whenever the needed quality of the images allows. Singer[38] found that, though the exposure rate of the mini C-arm is approximately 10% of that of a standard C-arm, surgeons tended to stand closer to the beam, which resulted in higher exposure than expected. Still, there is an estimated 1- to 2-fold reduction in radiation to the surgeon with mini C-arm, compared with standard C-arm, despite the mean increased number of exposures.[39-42]

Four methods have been recommended for reducing exposure from scatter radiation: decreasing exposure time, increasing distance, shielding (Table III), and contamination control.[43] The NCRP recommends that the surgeon stand at least 2 m (6.6 ft) away from the

Table I. Exposure Rates and Considerations of Common Pathogens

	Human Immunodeficiency Virus	Hepatitis B Virus	Hepatitis C Virus
Rate of percutaneous injury, %	0.3	6-30	1.8
Rate of mucocutaneous injury, %	0.09	Not quantified	Rare
Preexposure considerations	Prevention	Vaccination	Prevention
Postexposure considerations	Zidovudine	Hepatitis B immunoglobulin	None

Table II. Maximum Allowable Radiation Doses[a]

Annual total body (NCRP)	5
Annual total body (ICRP)	2
Embryo/fetus (>9 mo)	0.5
Eye	15
Thyroid gland	30
All other organs (including gonads)	50
Pediatrics	10% of adult dose

Abbreviations: ICRP, International Commission on Radiological Protection, NCRP, National Council on Radiation Protection and Measurements.
[a] data are represented as rem.

Table III. Radiation Shielding Methods

Protective Gear	% Radiation Attenuation
Leaded gowns	90 (0.25 mm), 99 (0.5 mm)
Glasses	30-70 (leaded), 20 (ordinary)
Thyroid gland shield	90
Radioprotective shield	7-50

patient so that the beam intensity is 0.025% of the beam intensity for the patient.[43] There are 2 options for leaded gowns: 0.25-mm gowns attenuate 90% of radiation and 0.5-mm gowns attenuate 99% of radiation, but weigh twice as much.[43] Leaded glasses provide 30% to 70% attenuation and ordinary glasses alone provide 20%. Eye protection is recommended, as radiation-induced ocular morbidities include transient erythema, vision loss, and even ocular tumors.[44,45] Thyroid gland shields 0.5-mm thick should also be worn; they attenuate approximately 90% of radiation.[43] Excessive radiation exposure to the thyroid has been shown to lead to thyroidal disorders, including adenomas, thyroiditis, hypothyroidism, and malignant neoplasms.[46] Wagner and Mulhern[47] found that radioprotective gloves provide exposure reduction of only 7% to 50% and were even less effective at high-energy levels. Protective gloves may cause more harm than good, as they can give surgeons a false sense of security, increasing the risk that they will put their hands in the direct line of the beam. Other exposure reduction techniques include using the low-dose option on C-arms when maximum resolution is not needed and using a laser guide to center the beam to avoid unnecessary off-center images.[32] Noordeen and colleagues[33] also found that when the surgeon (vs the technician) controls the C-arm foot pedal, there is a significant reduction in radiation exposure.

Exposure to Surgical Smoke

Use of electrical surgical units, commonly known as Bovies, has become routine in most surgical procedures. The cautery process creates smoke, which consists of approximately 85% water vapor and 5% chemicals and cellular debris, and is potentially harmful to surgeons and staff.[48] It is the potential carcinogenic, mutagenic, inflammatory, and infectious effects of the smoke that are of most concern. Investigators have found that Bovie smoke contains up to 80 different chemicals, including formaldehyde (irritant and potential carcinogen), acetaldehyde (carcinogen), benzene (carcinogen), and toluene (respiratory and eye irritant, and neurotoxin).[49,50] Gatti and colleagues[51] confirmed that Bovie smoke was mutagenic to certain bacteria and Wenig and colleagues[52] found changes in lung parenchyma, including alveolar congestion, blood vessel hypertrophy of varying degrees, focal emphysematous changes, and muscular hypertrophy of blood vessels in the lungs of rats exposed to Bovie smoke.

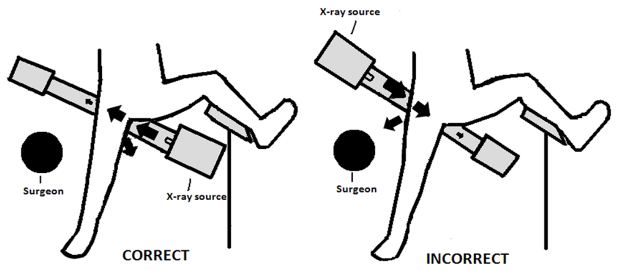

Figure 1. Proper C-arm positioning: Primary beam enters patient on side opposite to patient.

Both bacteria and viruses have been isolated from surgical smoke, raising the concern of potential infection secondary to the smoke. Bacteria identified in the smoke, include *Bacillus subtilus, Staphylococcus aureus,* and *Mycobacterium tuberculosis*.[53] Human papillomavirus and HIV have been identified in vapor from warts treated with an electrosurgical cautery device, but have not been found to be able to infect humans.[48,54,55] The viruses are large enough that they should not be able to penetrate the filters on surgical masks.[56]

Suctioning smoke near its source is most likely to prevent exposure and any associated health consequences.[56] Most surgeons use wall-mounted suction devices to extract Bovie smoke. However, research has shown that this measure is inadequate.[57] The US National Institute for Occupational Safety and Health recommends using a smoke evacuator system, a device designed specifically to remove and filter smoke from the operative field; this system can pull 1.42 m^3/min , has a capture velocity of 30.48 m/min to 45.72 m/min, and should be kept approximately 5.1 cm from the surgical site.[58] The filters on these devices must be changed regularly to ensure maximum effectiveness.

Exposure to Chemicals

Polymethylmethacrylate (PMMA) has been widely used in arthroplasty since the 1950s. Of all surgeons, orthopedic surgeons face the most risk for exposure of skin, respiratory tract, and neurologic system to the toxic effects of PMMA.[59] PMMA can induce skin sensitization in susceptible orthopedic surgeons who occasionally contact the monomer directly.[60] Although there is no pathologic evidence that PMMA is a respiratory

Table IV. Common Locations of Pain in Orthopedic Surgeons

Pain	% Surveyed
Neck	66
Neck with radiculopathy	29
Shoulder	49
Elbow	28
Wrist	26
Hand/finger	31
Low back	66
Low back with radiculopathy	29

Table V. Common Injuries Suffered by Orthopedic Surgeons

Diagnosis	% of Surveyed
Cervical disk herniation	24
Rotator cuff pathology	24
Lateral epicondylitis	17
Carpal tunnel syndrome	11
CMC/MCP joint arthritis	12
Lumbar disk herniation	20
Spinal stenosis	8
Varicose veins	20

Abbreviations: CMC, carpometacarpal; MCP, metacarpophalangeal.

sensitizer, cases of occupational PMMA-induced asthma have been reported.[61,62] In addition, slower nerve conduction velocities were found in the hands of dental technicians who routinely handled PMMA.[63] As a lipid solvent, PMMA can penetrate rubber gloves after a few minutes; it may be more dangerous to wear gloves than to work barehanded, as PMMA can become occluded between the glove and the skin.[63,64] While the cytotoxicity and carcinogenicity of PMMA have not been fully investigated, Bereznowski[65] observed that PMMA disrupted mitochondrial function in rat liver cells and Chen and colleagues[66] found it was toxic to human neurons in vitro. Epidemiologic and chromosomal studies, on the other hand, have shown little to no evidence that PMMA is carcinogenic or mutagenic.[67-71]

The World Health Organization[60] (WHO) proposed measures to minimize occupational exposure to PMMA. WHO advises individuals to avoid direct contact with PMMA and to wear appropriate personal protective equipment, consistent with infection control guidelines. However, as indicated earlier, rubber gloves provide minimal protection at best.[63,64] WHO also suggests using PMMA in a well-ventilated area and installing recirculating-room-air filters with gas absorbents of acid carbon.[60]

Orthopedists are also often exposed to isocyanate, a chemical in both plaster and fiberglass casts. Isocyanates are potent allergens that can cause asthma, hypersensitivity pneumonitis, contact dermatitis, and rhinitis.[72,73] There is at least 1 reported case of a cast technician developing asthma after being exposed to isocyanates.[74] Sensitization can occur from skin exposure. Although there is limited evidence that isocyanates can penetrate gloves, use of gloves is still recommended to protect against isocyanate exposure, with nitrile gloves preferred over latex gloves.[75-77]

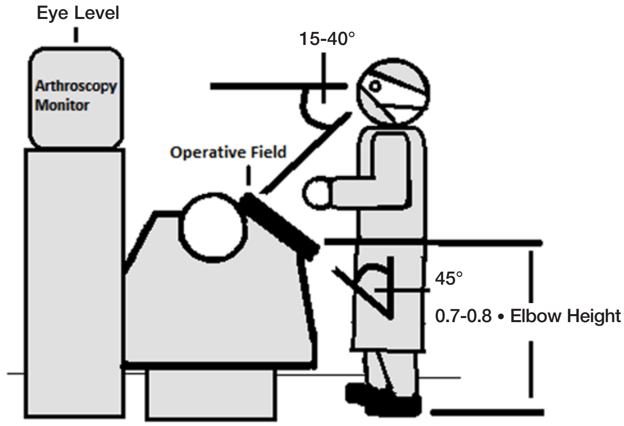

Figure 2. Ideal operative field positioning: Operative height at 0.7-0.8 • elbow height. Gaze angle at 15° to 40° below horizontal. Operative field at 45° to torso. Arthroscopy monitor at eye level.

Exposure to Noise

When using power tools, orthopedic surgeons are exposed to noise levels that increase their risk for noise-induced hearing loss (NIHL). NIHL may be temporary but can become permanent, requiring a hearing aid, and it may be accompanied by tinnitus. Willett and colleagues[78] found that 50% of orthopedic personnel with long-term exposure to power instruments showed early signs of NIHL.

The US National Institute on Deafness and Other Communicable Disorders reported that prolonged exposure to noise of 90 dB can cause gradual hearing loss and that regular exposure to noise of 110 dB for longer than 1 minute risks permanent hearing loss. The US Occupational Safety and Health Administration (OSHA) defined noise exposure as hazardous when the level is 85 dB and the duration is 8 hours per day; the allowable duration is reduced by half for each 5-dB increase.[79] Many investigators have conducted studies to quantify the level of noise pollution to which surgeons are exposed. In investigating total knee and hip replacements, Love[80] found a mean noise level between 74.8 and 82.1 dB. Mullett and colleagues[81] investigated different instruments and found maximum noise levels ranging from 88 to 142 dB (5 cm away) and 71 to 96 dB (2 m away). Willett[78] determined that orthopedic saws and drills produced noise levels ranging from 90 to 100 dB (at operator's ear) and 80 to 90 dB (3 m away). Ray and Levinson[82] found noise levels up to 118 dB during use of high-speed gas turbine bone-cutting drills and found that suction tips with tissue trapped inside created a whistling noise of up to 96 dB.

The noise level in an operating room consistently exceeds the 8-hour level set by OSHA, but hearing loss is likely not as rampant in orthopedic surgeons given the intermittent nature of this exposure.[83] Nevertheless, minimizing noise exposure is important. Although some may be reluctant to do so, surgeons should undergo regular audiometric testing and wear hearing protectors, such as ear plugs, particularly when powered devices are being used.[80] At least 1 study found that a particular company's saw had a reduced noise level (81.6 vs 88.9 dB); companies should be encouraged to continue advancements in this area.[84]

Musculoskeletal Injury

Orthopedic surgery places more physical demands on surgeons and their assistants. The high demands involved in retracting, using tools, and simply holding a limb in a constant position can result in musculoskeletal injuries. Surgeons are also required to remain standing for prolonged periods of time, and operating in potentially nonergonomic positions can create even more physical stress. Orthopedic surgeons need to be aware of these issues so that they can take precautions to prevent musculoskeletal injuries.

Mirbod and colleagues[85] found that orthopedic surgeons have more subjective reports about physical injuries than general surgeons. The most commonly injured areas are the back, neck, shoulders, arms, and hands. In a survey of spine surgeons, Auerbach and colleagues[86] reported an extremely high incidence of low-back, neck, shoulder, elbow, wrist, and hand pain (Table IV). In addition, the incidence of cervical and lumbar disk herniation with radiculopathy, lateral epicondylitis, and carpal tunnel syndrome was higher in those surveyed than in the general population (Table V). Surgeons' use of nonergonomic devices can generate unnecessary additional stress.[87] Forst and colleagues,[88] for example, found that surgeons who used the Kerrison rongeur were nearly 3 times more likely to develop carpal tunnel syndrome. Nevertheless, static stress caused by non-neutral postures can lead to fatigue and disability as much as dynamic stress can. Rademacher and colleagues[89] found that approximately 70% of intraoperative orthopedic postures are substantially static; much of the back and neck pain is likely caused by frequent and prolonged static head-bent and back-bent postures.[90]

The regularity of arthroscopic procedures creates additional stress for orthopedic surgeons. Although there is little research on the ergonomics of arthroscopy, the ergonomics of laparoscopy has been studied. Park and colleagues[91] found that 87% of surgeons who regularly performed minimally invasive surgery had performance-related symptoms. Arthroscopic surgeries present challenges that do not exist in open surgeries. As use of arthroscopic instruments requires that the surgeon remain visually fixed on a screen, neck and back movements are kept to a minimum, which can lead to stiffness.[92-94] Similarly, arthroscopy has fewer degrees of freedom, leading to more frequent awkward movements of the upper extremities.[92] Laparoscopic procedures have higher peak and total muscle effort for forearm and thumb muscles than open procedures do, and there have been case reports of collective nerve injuries to the hand and thumb associated with use of laparoscopic instruments, reflecting the need for surgical instruments with more ergonomic designs.[95-97] Additional studies are needed to determine whether the hazards of laparoscopy correspond to the hazards of arthroscopy.

To avoid these injuries, orthopedic surgeons must operate with more ergonomic instruments and must adopt standing postures that keep the body in its most neutral position. Although differences in hand size have been well understood, surgical instruments are still being produced "one size fits all." Ideally, they should be improved for ergonomic ease.[91] Surgeons can take specific actions to maintain ideal posture. Many of these actions simply involve positioning patients differently. Optimal operating height is 0.7 to 0.8 times the elbow height of the surgeon. The patient should be positioned as close to the surgeon as possible, and the surgeon's gaze angle should be 15° to 40° below the horizontal. The operative field should be kept 45° to the surgeon's torso and during arthroscopic procedures, the monitor should be positioned to allow the surgeon to maintain a neutral posture (Figure 2).[98,99] Other actions surgeon can take include frequent position changes, particularly during arthroscopic procedures, short breaks for stretching, and, when possible, use of a stool or a footrest.[98]

Emotional and Psychological Disturbances

It is well established that physicians are under a high degree of emotional and psychological stress. Prolonged sleep deprivation, significant job demand, and high level of responsibility lead to elevated rates of depression, suicide, drug abuse, alcoholism, marital disruption, and burnout in residents and practicing physicians, particularly surgeons.[100-105] Few studies have been conducted specifically with orthopedic surgeons, but clearly, these physicians face these issues as well.

Burnout, the leading result of emotional disturbance experienced by physicians, "is a syndrome of emotional exhaustion, depersonalization, and reduced sense of per-

Table VI. Risk of Burnout in Orthopedic Surgeons

	High Range of Emotional Exhaustion, %	High Range of Depersonalization, %	Low Range of Personal Accomplishment, %
Residents	32	56	18
Faculty	28.4	24.8	10
Chairpersons, program directors	36-52	24-33	0-4

sonal accomplishment occurring in individuals who work in human services."[106] Sargent and colleagues[107] surveyed orthopedic residents and faculty, and Saleh and colleagues,[108] orthopedic chairpersons and program directors regarding quality of life (Table VI). At highest risk for burnout were residents, followed by chairpersons and program directors, and then faculty. These studies showed an improvement in burnout in residents but an increase in burnout in faculty after implementation of 80-hour work restrictions.[109,110] In addition, there was a significant improvement in emotional exhaustion after these restrictions were implemented, but only a slight improvement in depersonalization. Burnout was found at higher levels in younger faculty and in those who had been practicing fewer than 10 years.[107]

Sargent and colleagues[107] also examined psychological distress, marital dysfunction, and personal stress levels. Psychological distress was found in 16% of residents and 19% of faculty, which is slightly higher than the 13% rate of depression found among all physicians.[111] These higher rates are of concern given that physicians are 2 to 3 times more likely to commit suicide than the general population.[101] Most residents were functioning well in terms of maintaining relationships, but, compared with faculty, they reported less satisfaction with work–life balance and more work interference with home.[107] Having well-functioning relationships is correlated with less emotional exhaustion and a higher sense of personal achievement.[107,112] Overall stress levels were higher in faculty than in residents, likely because of increased responsibility. Faculty perceived less support from their peers and department than residents.[107]

Risk factors associated with burnout and marital status include high levels of sleep deprivation, anger, loneliness, regular alcohol use, anxiety, or work–life conflict.[107] Protective factors include perceived support from other medical families, separation of personal and work life, time alone with mate, supportive work environment, in-program or colleague mentor, religion or faith, regular time for exercise, hobbies or meditation, non–work-related vacations, and little alcohol use.[107]

Conclusion

Orthopedic surgeons are subjected to a multitude of occupational hazards. Many of these surgeons face higher risks than other medical and surgical specialists. These risks often include infectious, radiational, chemical, physical, and psychosocial hazards. Risk management has become influential in most hospitals and guidelines are set to minimize harm to health care workers. To avoid potential harm, orthopedic surgeons must follow established guidelines, take basic preventive measures when possible, and be conscious of these risks when they arise.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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