Doug Elizondo
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Basic Ergonomics

Ergonomics is about finding a better fit between people and the things they do, the objects they use, and the environments in which they live, work, travel, and play.

The science of ergonomics is the study and application of human anatomy, biomechanics, and biology to the design of objects, systems, and environments. Also called human engineering, or human factors engineering, it is a relatively new branch of science that was founded in 1949, spurned by the development of new technologies during World War II. Throughout this period, it had become clear that, in order to be used safely and effectively, new technologies and products needed to account for human and environmental factors. Over the past 50 years, ergonomics has become widely applied, from factory work and information systems to the home, sports, and leisure -- just about every aspect of life (Pheasant, 1991).

In the workplace, the goal of ergonomics is to improve efficiency, quality, and job satisfaction by making routine and repetitive tasks more comfortable and easier to do. This reduces stress, both physical and psychological, by lowering the fatigue factor and human error. In some jobs, particularly in the nuclear and chemical industries and transportation (e.g. air traffic control), the cost of human error can be catastrophic, injuring or killing hundreds of people or resulting in widespread environmental disasters.

For the vast majority of jobs, however, it is the individual workers who are primarily affected, suffering discomfort, injuries, or outright disabilities, classified as work-related musculoskeletal disorders (MSDs or WMSDs). MSDs are medical conditions affecting the muscles, nerves, tendons, ligaments, joints, cartilage, and/or spinal discs. MSDs are referred to by a number of names (and acronyms). The terminology includes Repetitive Strain Injuries and Repetitive Stress Injuries (RSIs), Cumulative Trauma Disorders (CTDs), and Overuse Syndrome, although these are umbrella terms and don't refer to any MSD in particular (Pheasant, 1991). Some examples of specific MSDs are carpal tunnel syndrome, tendonitis, ganglion cysts, and lower back pain. General warning signs of MSDs are fatigue, stiffness, persistent burning or aching, reduced coordination, and a loss of grip strength in the hands.

Numerous studies have established the following ergonomic risk factors as most likely to cause or contribute to an MSD: force, repetition, awkward postures, static postures, vibration, contact stress, and cold temperatures (Putz, 1992). Of these risk factors, force (i.e., forceful exertions), repetition, and awkward postures are most often associated with the occurrence of serious MSDs.

Exposure to one ergonomic risk factor may be enough to cause or contribute to an MSD. Most often, ergonomic risk factors act in combination to create a hazard. Jobs that have multiple risk factors have a greater likelihood of causing an MSD, depending on the duration, frequency, and/or magnitude of exposure to each factor. It is important to consider ergonomic risk factors in light of their combined effect in causing or contributing to an MSD, as well as their individual effects (McCormick and Sanders, 1993).

Ergonomics has become a topic of increasing importance in the workplace throughout the past several decades. A mismatch between the physical capacity of workers and the physical demands of their jobs can result in MSDs. In the USA, 1.8 million workers report work-related MSDs such as carpal tunnel syndrome, tendonitis, and back injuries, every year. Approximately 600,000 MSDs are serious enough to warrant taking time off from work to recover and sometimes even require surgical intervention. Evidence suggests that another 1.8 million MSDs go unreported every year (Erickson and Hoskins, 1998).

MSDs are estimated to cost up to $50 billion a year. Employers pay between $15-$18 billion in workers' compensation costs alone; $1 out of every $3 spent on workers' compensation goes for MSD-related claims. This does not include billions of dollars spent on medical treatment and hidden costs associated with work-related injuries (Erickson and Hoskins, 1998). Recent increases in reported MSDs suggest that employers should be vigilant in creating work environments that are conducive to both good health and high productivity.

The Microscope Problem

At Raytheon, solder operations with the use of the microscope have accounted for many of the work-related MSDs that have been recorded thus far in 2005. Electronic assemblers use tools or procedures that require repeated pinched gripping and/or wrists and forearms in awkward positions causing soreness in the hands, wrists, shoulders, and back. Tools are sometimes placed to far away requiring extended reaches resulting in back and neck soreness. At times, assemblers have to work hunched over because the chair, work surface or microscope is not properly positioned or designed resulting in back and neck soreness. Operating a microscope for extended periods of time, places a significant amount of strain on the neck, shoulders, eyes, lower back, and arm/wrists. Associated risk factors include:

- Awkward and static posture of the lower back
- Lack of adequate leg and knee clearance under work station
- Working with elbows winged
- Pinch grip when adjusting binocular eyepiece
- Wrist and palm contact pressure in the carpal tunnel area.
- High repetition
- Eye strain and fatigue
- Awkward and static posture of the neck and head

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Ergonomic Timeline for Microscopy

People who use microscopes have been asking those who design them to make them more suitable for human use ever since that first user sat down at one and tried to spend an entire workday peering through the eyepiece. Some of these requests have taken the form of articles presented in public-domain publications concerning the adverse health impact of operating these tools throughout a career. The excerpts below are just the tip of the iceberg.

1. Treatise On Optics, Second American Edition - Philadelphia, **1835** Sir David Brewster: "The best position for microscopical observations is when the observer is lying horizontally on his back. .... The worst of all positions is that in which we look downwards vertically."

2. The International Academy of Cytology, Reference 25:195-196, **1981**, letters to the Editor: ..."The principles of industrial design have long been established, and it is axiomatic that tools should be adapted to people and not vice versa. In addition, microscopy is a skill that could readily be practised by many handicapped people if instruments could be made to suit their special requirements, such as mounting on wheel chairs." Max Robinowitz, M.D., Gunther F. Bahr, M.D. F.I.A.C., Cecil H. Fox, Ph.D. (Armed Forces Institute of Pathology)

3. Proceedings of the Human Factors Society - 29th Annual Meeting - **1985** Article: "Physical Stress Reduction of Microscope Operators" ..."Soderberg, et al. (1980) also revealed that 84 percent of microscopists had job related musculoskeletal pain." Kwan S. Lee and Linda A. Humphreys.

4. Applied Ergonomics 1991 - 22.1, 36-42 Article: "Planning and Implementation of Microscope Work" ..."A study by Helander and Prabhu (**1987**) reported an OSHA injury rate of 19 for a sample of microscope operators." M.G. Helander, E.J. Grossmith and P. Prabhu.
(note: OSHA rate of 19 means that 19% of employees missed work during the year as a result of on-the-job injury.)

5. ASCT News (American Society for Cytotechnology) Number 3, **1990** Article: The Scoop on Scopes ..."When one considers physical discomfort as an adjunct to low salaries it becomes increasingly apparent why there is a high incidence of "drop-out" at the fifth through tenth year of practice among cytotechnologists." Roberta M Goodell, Editor.

6. USA Microscopy & Analysis, July **1993** Article: "Applying Ergonomics to Improve Microscopy Work" ..."For example, in their study of a major U.S. Company, Emmanuel and Glonek found that 80 percent of microscopists experienced headaches or neck aches and 75 percent complained of eye strain." Helen Haines and Lynn McAtamney.

7. Research & Development, June **1995**, feature article -- "Fabs Strain to Prevent Work- Related Injuries" from Don Lassiter, a consultant on occupational safety and health issues for the Semiconductor Industry Association (SIA) "The top candidates in the fab for work-related injuries are maintenance technicians, microscope technicians, and material handlers." He recommends microscopes with computer monitors and microscopes designed to improve ergonomics for routine inspection tasks.
(note: the semiconductor industry employs 200,000 in the U.S. with an injury rate of 4.0 per hundred in 1993. (Source: Tritek, 2005).

Microscope Ergonomics

The human body is a wonder of biomechanics, accommodating and adapting to a wide variety of postures and activities. The keyword for a healthy, well-maintained body is "activity." The human body works best when it is constantly moving or changing positions (Vratny, 1999).

Sitting or standing for hours on end, bent over a microscope eyepiece is not an activity for which the body is well adapted. Microscope work requires the head and arms to be held in a forward position and inclined toward the microscope with rounded shoulders, a posture that can irritate soft tissues, such as muscles, ligaments, and disks. If the feet are placed on the ring-style footrests that are common to many lab stools, the position is further exaggerated.

Poor posture and awkward positioning are the primary risk factors for MSDs that can affect full-time assemblers, who often experience pain or injury to the neck, wrists, back, shoulders, and arms. Eyestrain, leg, and foot discomfort have also been documented with long-term microscope use. In the semiconductor industry, the second leading cause of work-related medical problems is found in microscope technicians, trailing only maintenance workers who traditionally have high injury rates (Gschwendtner and Kreczy,1999). A regional survey of cytotechnologists, heavy users of microscopes, found that slightly over 70 percent reported having neck, shoulder, or upper back symptoms, while 56 percent had an increased incidence of hand and wrist symptoms. Other studies have indicated that around 80 percent of microscope users in all fields have experienced job-related musculoskeletal pain and that 20 percent have missed work because of medical problems related to microscope use.

Percentage of Medical Problems Reported by Microscope Operators

Anatomical Location	Employee Percentage
Neck	50-60
Shoulders	65-70
Back (Total)	70-80
Lower Back	65-70
Lower Arms	65-70
Wrists	40-60
Hands and Fingers	40-50
Legs and Feet	20-35
Eyestrain	20-50
Headaches	60-80

Table 1

The rather high 5 to10-year drop out rate for cytotechnologists is attributed, in part, to physical discomfort associated with long hours examining specimens through the microscope. Table 1 above, lists the range of percentages reported in the literature for medical complaints associated with long-term microscope use. A majority of reported problems occur with the neck, back, shoulders, and arms, with a smaller percentage of microscopists reporting discomfort or injury to the wrists, hands, legs, feet, and eyes. Many of these conditions can be avoided or at least mitigated (Hunting and Kalavar, 1996). Two studies at Duke University Medical Center during the 1990s suggested that people suffered fewer discomforts when using new ergonomically designed microscopes or even conventional microscopes modified to better accommodate the user. In either case, adaptability was the key. Microscopes that could be adapted to an individual user, rather than forcing the user to adapt to the microscope, were more comfortable and caused fewer problems (Cohen and Marcus,1997).

Factors believed to be causing these problems are head inclinations up to 45 degrees and upper back inclination at angles up to 30 degrees, awkward positioning of the arms and hands, and repetitive motions (Guteri, 1997). An unaccommodating workstation that requires a microscopist to sit in awkward positions for long periods can also cause fatigue and MSDs.

The major factor with using conventional microscopes is that viewing specimens requires users to maintain a flexed neck posture while the hands are in a relatively fixed position. From the viewpoint of biomechanics, having to maintain even a slight incline of 30 degrees from the vertical can produce significant muscle contractions, muscle fatigue, and pain. In fact, it has been documented that nerves can often be pinched when the neck is overextended by this amount. Repetitive motions of the hands and the contact stress of arms resting on a hard surface can cause pain and nerve injury, leading to repetitive stress injuries and/or carpal tunnel syndrome (Yassi, 1997).

Tilting and Telescoping Observation Tube and Eye-Level Riser

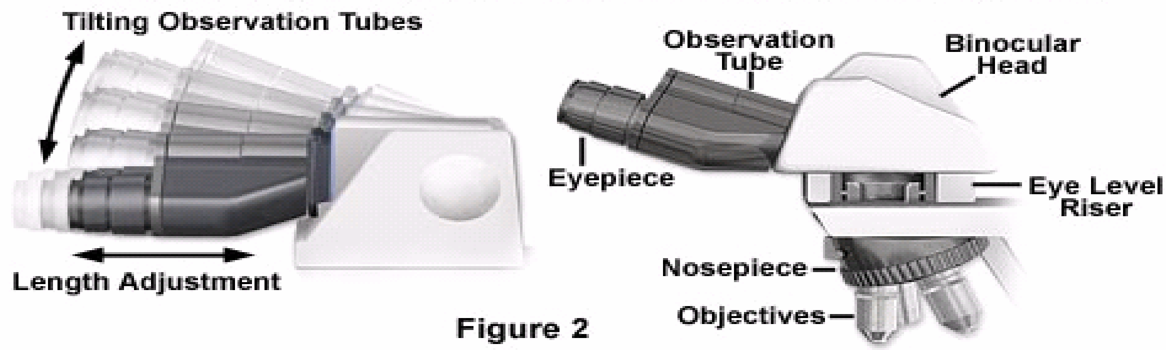

Figure 2

Source: Raytheon EHS

Later studies have suggested that to permit a more neutral erect working posture, the optical path (distance from the ocular lenses to the specimen being viewed) should range between 45 and 55 centimeters (18 to 21.5 inches). The eyepieces should be no more than 30 degrees above the horizontal plane of the desktop. A majority of older microscopes, however, have much shorter optical path dimensions (25 to 30 centimeters or 10 to 12 inches) with the eyepieces angled at 60 degrees above horizontal (Haines and McAtamney, 1993).

This creates a dilemma for the user. If the microscope is raised high enough to prevent neck flexion, then the user is forced to bend the wrists into an unnatural position. If the microscope is lowered to bring the stage to a more neutral position, with the forearm parallel to the floor, then the neck is forced to bend. Most workers compensate for this by finding some "happy medium" between the two extreme postures, resulting in discomfort for the neck, shoulders, forearms, wrists, and hands.

Eye fatigue can also be a major problem for operators, especially if they have poor vision resulting from near and far sightedness or astigmatism. The diopter adjustment provided on most microscope eyepieces can be employed to compensate for minor focus problems (near and far sightedness), but microscopists who have moderate to severe astigmatism should wear glasses even when viewing specimens through the eyepieces. In order to accommodate the longer eyepoints necessary for observation with eyeglasses, manufacturers offer specialized high eyepoint eyepieces. Many problems associated with eyestrain during extended periods of microscope use can be alleviated by employing video camera systems that display the specimen on a computer monitor or television screen. In fact, many future microscope designs may be capable of eliminating the eyepieces altogether, substituting instead a CCD or CMOS image sensor for the classical observation tubes. The digital imaging chip will be coupled to a sophisticated software analysis package that controls image capture and storage, digital processing, and other features such as time-lapse cinemicrography and real-time video movies (Haines and McAtamney, 1993).

Ensuring that the microscope images are as bright, sharp, and crisp as possible will also help to reduce eye fatigue and associated headaches. It is important to train operators in correct alignment of the microscope lamp and optical pathway to optimize image quality. This is true regardless of whether the image is observed through the eyepieces or on a computer monitor. Many of the newer microscopes have expanded view fields through the use of eyepieces with larger field diaphragms. Coupled to objectives with higher numerical aperture values, better aberration correction, and longer working distances, the images produced show a tremendous amount of specimen detail in exquisite clarity with flat fields from edge-to-edge. These factors ease the burden of visually searching for tiny specimen details, and reduce associated eye stress and fatigue during extended periods of observation.

Some companies now produce adapters that allow conventional microscopes to be modified to better fit individual users. Body tube extensions can increase the distance between the eyepieces and stage adjustments, and optical wedges can provide a greater angle of adjustability, between 30 and 80 degrees. Aftermarket microscope stands allow an instrument to be elevated and rotated for increased comfort.

A recent solution to the problem of microscope usability has been the incorporation of ergonomic features into modern designs by the microscope manufacturers. Although these models were prohibitively expensive for the vast majority of labs when they were first developed, ergonomic features are increasingly becoming standard on new microscope models. New designs are significantly more comfortable in the neck and shoulder regions, indicating that redesigning microscopes with posture and ease of manipulation in mind will help to reduce discomfort associated with long hours of use. Symptoms of eye fatigue and mid-back discomfort could be reduced as well, though not to a statistically significant degree (Johnson, 1997). Eliminating or reducing eye fatigue is most easily accomplished by equipping the microscope with a digital video camera that displays specimen images on a television screen or computer monitor. As mentioned above, this allows operators who have eye problems, such as myopia and astigmatism, to comfortably wear their glasses during inspection of specimens.

Prevention

Peering down vertically through a microscope is "the worst of all positions" for making observations. Operators lying on their backs may not be entirely feasible, but it does capture one essential truth. The body can endure stationary positions for extended periods if it is in a neutral posture, a position that can be maintained without a concerted effort or contortions. A neutral body posture is essential to working efficiently and effectively at the microscope for long hours.

Not everyone is in a position to buy a new ergonomically designed microscope or workstation. For conventional microscope workstations, the key is finding ways to modify them to fit the user rather than forcing the user into awkward positions.

Following are some basic guidelines for achieving and maintaining neutral body posture while using a microscope:

- Eyes - eyepieces should rest just below the eyes with the eyes looking downward at an angle 30 to 45 degrees below the horizontal; interocular distance of binocular eyepieces should be adjusted to ensure that both eyes are focusing comfortably.
- Neck - the neck and head should bend as little as possible, preferably no more than 10-15 degrees below the horizontal.
- Back - the individual should be sitting erect, leaning the entire body slightly forward with the lower back and shoulder blades supported by the chair and/or lumbar support cushion. Sitting for long periods places undue strain on the lower back, which can be alleviated with the proper support.
- Arms/wrist - the upper arms should be perpendicular to the floor, elbows close to the body (not winged or sticking out), the forearms parallel to the floor; wrists should be straight.
- Legs - feet should rest firmly on the floor or a footrest, and even pressure should be applied by the chair to the back of the thighs.

To further reduce ergonomic risk factors:

- Develop an awareness of posture. Try to maintain the natural curve of the lower back when sitting. Use additional lumbar support if necessary.
- If the foot ring on a lab stool is too low, raise it to keep the lower back supported by the chair back. Often, laboratory bench leg-wells are utilized as storage facilities for seldom-used equipment and extra supplies. Clear this area so that legs and feet are not impeded while sitting at the bench.

- Don't lean forward to look through the microscope. Instead, adjust the position of the chair, workstation or microscope to keep the back straight and the headupright. The eyepieces should be in line with, or even extended over, the edge of the bench.
- If the microscope is too low, raise it by placing a book underneath it or modify the configuration with OEM or aftermarket accessories to keep the head upright. If microscope eye-level risers are not readily available, use a three-ring binder to tilt the microscope so the eyepieces are placed at a more suitable angle. For a long-term solution, either purchase a suitable OEM or aftermarket stand or have the local physical plant construct one adequate for the purpose.
- Adjust the height of the microscope, bench, or chair to avoid bending or extending the neck, or jutting the chin forward. If standing, the operator should have anti-fatigue mats installed at the microscope workstation to ease the burden on the feet, legs, and lower back.
- Check the seat platform for tilt and height to maintain even pressure along the back of the thighs. In situations where it is possible, use an industrial-height footstool for better posture and position. This allows the operator to bend forward at the hips rather than the neck, back, and shoulders.
- Avoid contact stress from forearms resting on sharp bench or counter edges by adding padded edge protectors. Operating the focus and stage controls with the arms separated from the bench (lifted) for extended periods can induce static loading fatigue, which can be reduced with the proper support, such as padded and tilted armrests. Also, if laboratory geometry permits, utilization of cut-out work tables or laboratory benches with recessed tops allow the operator to spread out and more efficiently employ auxiliary equipment necessary for microscopy observations and manipulations.
- Ensure the microscope optical train is configured properly and the illumination source is aligned and performing at capacity. Adjust eyepiece interpupillary distance, diopter settings, and check the parfocality. The eyepieces should be approximately the same distance from the observer's eyes, rather than one being closer than the other. Eyepoints should be high enough that the field of vision is completely filled, but far enough away so as to avoid contact of eyepieces with the eyelashes. If the eyepieces are not properly focused, the eyes tend to compensate, which leads to increased headaches and eye fatigue. Buy plan-corrected objectives that produce flat viewfields. Microscopes with significant field curvature are difficult to use, especially for extended periods of time in which the operator must be continuously refocusing the specimen to examine the entire field. Excessive microscope illumination can cause an uncomfortably high level of light and contrast, which is easily reduced by proper configuration of the lamp voltage and the condenser aperture. All of these factors are the primary cause of eyestrain.

- Operators that wear eyeglasses can adjust the eyepieces to accommodate near and far sightedness, but those who have more severe conditions should see an optician to determine whether they are suited for extended observation periods using a microscope. Simple adjustment of the eyepiece diopter cannot correct for astigmatism and some of the other, more serious, visual difficulties. In cases of extreme astigmatism and fusion insufficiency (poor eye coordination), the operator may require assistance of digital video equipment and a computer monitor or television screen to enhance, or replace, the eyepieces.
- Check the laboratory environment for excessive glare and reflections from overhead fluorescent lighting, and adjust external and internal microscope light to compensate for this artifact.
- Other environmental factors such as temperature, humidity, air currents, ventilation, excessive noise, and ambient lighting levels will also affect operator comfort and fatigue, especially over extended periods of time. Adjust these variables, whenever possible, to make the laboratory environment as comfortable as possible. The nominal temperature range should lie between 19 and 23 degrees Centigrade (66 to 73 degrees Fahrenheit), with a relative humidity averaging between 40 and 60 percent. Low humidity conditions lead to drying of the eyes, which further aggravates eyestrain.
- Regular breaks from the microscope, ranging from five to ten minutes per hour, are essential to reduce fatigue, especially for operators who work at microscope workstations for six to eight-hour shifts. Periodic resting of the eyes, neck, and shoulders allows operators to work for extended periods without experiencing stress-related injuries. Bending, flexing, rotation, extension, and stretching exercises during these breaks often helps to alleviate stress and will greatly benefit the operator's health in the long term. In fact, some companies have implemented a routine exercise program during short break periods. Another mechanism employed to relieve fatigue is to intermix other duties on a regular basis to reduce the length of microscopy sessions.

The amount of time a microscopist spends at a workstation should be taken into account when evaluating workstation modifications. The minimum requirement for all seated workstations is good seating, with an adjustable chair and a footrest if necessary; anti-fatigue mats should be used for workstations that require the microscopist to stand. The chair should have a pneumatic, adjustable seat pan with a sloping "water fall" edge, a backrest that is adjustable for both height and angle, height adjustable armrests, and a five star base with caster wheels.

For some seated workstations, a footrest may be appropriate. It should provide stability and firm contact with the floor and a surface texture that keeps the feet from sliding off. It should be readily adjustable to accommodate varying user heights and have an angle of approximately 10 degrees. Toes should be above the heel, allowing the lower leg muscles to stretch (Helander and Prabhu, 1991).

Additional recommendations based on time spent per day at the microscope:

1-2 hours/day

- Adequate clearance (a minimum of 2 inches) between the thigh and desk or counter with the leg-well free from obstructions.

2-4 hours/day

- Microscope tilted slightly forward or utilization of wedges, extenders, and/or eye-level adjustments.
- Proper arm support, keeping the limbs close to the body with the forearm parallel to the floor and resting on the bench top. Use armrests for older microscopes having controls located in high positions.
- Padded edges for workstations or countertops to avoid contact stress on arms.

4-6 hours/day

- Adjustable microscope eyepieces should be installed, if possible.
- Electrically powered focus adjustments and objective rotation if more than half the total time on the microscope is spent twisting the coarse and fine knobs while transitioning the magnification factor.

6 hours or more/day

- Adjustable microscope eyepieces and ergonomically positioned microscope controls.
- Electrically powered focus and objective rotation. If configurations permit, powered control of the condenser aperture diaphragm, illumination intensity, and beamsplitters.
- Video monitor or television screen for examination of repetitive specimens (the monitor should be placed in the operator's primary field of view).
- Easily adjustable work surface variables, such as bench height, armrest base angle, observation eye-level, and microscope height (essential in a multi-user workstation environment).

Microscopists can also benefit from general workplace ergonomics. Reduce fatigue by reducing or eliminating highly repetitive tasks and take micro-breaks, 20-180 seconds at 10 to 15 minute work intervals. Use this time to stand and/or stretch, and allow the eyes to focus at a distance. Objects that must be accessed frequently should be kept close enough to avoid having to stretch and strain, usually within a distance of 9-19 inches.

Less frequently utilized objects can be kept at a distance of 9-25 inches (Helander and Prabhu, 1991).

Conclusion

OSHA is continuing to formulate new ergonomics standards that will require employers to assess employee exposure to ergonomic risk factors in general industry jobs. The governmental organization estimates that the new standards, if implemented, will save employers $9.1 billion annually for the next 10 years, and prevent 460,000 reported MSDs a year (perhaps even more, if unreported cases are included).

Among the concerns of OSHA officials is that basic information about common MSDs, risk factors, and the importance of reporting symptoms be impressed upon employees who must spend a significant portion of their work day on the microscope (OSHA, 2005). Although many of the ergonomic requirements are now being addressed by microscope manufacturers, there are a considerable number of microscopes "in the field" that are poorly equipped to provide worker comfort and reduce the incidence of injuries. Over time, these microscopes will be replaced with modern, ergonomic-friendly versions, but in the meantime, employers should be concerned about potential medical problems that may arise from extended microscope use. If a worker's job routinely involves exposure to one or more of five known ergonomic risk factors: repetition, force, awkward postures, contact stress and vibration, then some adjustment of the work environment is necessary. Aftermarket accessories, which are available for a wide spectrum of microscopes, may be the answer for a majority of older instruments in the interim. However, the end result should be migration to microscopes designed to optimize both operator safety and comfort, while providing the latest features in regard to optical quality and performance.

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