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Case Studies

Ergonomic Evaluation of Antenatal Ultrasound Testing Procedures

Dawn Tharr, Column Editor

Reported by Daniel J. Habes and Sherry Baron

Introduction

On February 1, 1999, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from the safety manager of a university of medicine and dentistry. The request stated that ultrasound technologists at one of the university's antenatal testing units were experiencing neck, shoulder, and arm pain from performing transabdominal and transvaginal sonograms on pregnant women.

March 9–11, 1999, NIOSH representatives conducted a site visit at the university hospital's antenatal unit. The site visit included an opening conference with management and union representatives, the videotaping of several ultrasound procedures, and the distribution of a musculoskeletal disorders symptom questionnaire/body map to the ultrasound technologists.

Background

The antenatal testing unit is primarily a referral center that specializes in high-resolution ultrasound procedures. These tests are often extensive and lengthy. The clinic also receives routine referrals from gynecologists and other facilities that cannot perform these comprehensive procedures that are a specialty of the facility. The most common procedures performed are biophysical profiles, complete fetal evaluations (Level II exams), and Doppler studies.

Job Descriptions

The antenatal testing unit employs 11 ultrasound technologists and 2 perinatal physicians. A typical work schedule is five days per week, with seven scanning hours per day. During a typical workday, each sonographer performs about 10 ultrasounds, most of which are transabdominal. Sonographers are trained to perform both transabdominal and transvaginal examinations.

Work Area Description

Ultrasound procedures are performed in a room equipped with an examination table (bed) for the patient, a chair or stool for the sonographer, and an ultrasound imaging system. The six examination rooms at the clinic are not all configured the same. The ultrasound system is a free-standing machine on wheels, with a keyboard, monitor, and other controls. The keyboard and monitor are not height-adjustable, but on some units the monitors can be adjusted for tilt. Throughout the six rooms, keyboard heights range from 36 to 38 inches, and mid-screen monitor heights range from 47 to 53 inches. Some rooms have adjustable chairs with arms and backrests, while others have standard stools. The stools are height-adjustable by loosening a knurled knob that is difficult to turn. Five of the six examination rooms have a standard examination table that is 32 inches high and 27 inches wide, which is not adjustable and cannot be moved. The examination table in the sixth room is a 24-inch-wide stretcher on wheels; its height can be adjusted from 30 to 37 inches using a foot pedal.

The ultrasound images are captured with a transducer or sensor called the "scan head." For transabdominal scans, the scan head used is oval-shaped, 3 inches wide, about 4 inches long, and 1 inch thick. The transducer used for transvaginal scans is long and thin with a small imaging sensor at the tip and an inline handle at the other end.

Methods

Ergonomic

The ergonomics evaluation consisted of observation and several videotapings of the two types of ultrasound procedures. The video tape served to document and measure the visible aspects of the ultrasound procedures, such as postural demands, sustained application of muscular force, and repetitiveness for the sonographer; enable the input of body position data into computerized biomechanical models; and extract information from the video through playback analysis.

Work station and work area measurements were made with a tape measure, and the force to press down on a patient's abdomen with the scan head was simulated using a push/pull force meter.

Medical

The employee health staff of the hospital previously conducted complete medical evaluations of the ultrasonographers, which included a comprehensive questionnaire and musculoskeletal examination. The staff documented several shoulder and hand disorders, therefore, the medical portion of this HHE was limited to a brief symptom survey with a body map discomfort diagram. The ultrasonographers who were present during the evaluation were asked to indicate on the map the areas of the body in which they experienced pain or discomfort.

Evaluation Criteria

Overexertion injuries, such as low back pain, tendinitis, and carpal tunnel syndrome are often associated with tasks that include: (1) repetitive, stereotyped movement about the joints; (2) forceful manual exertions; (3) lifting; (4) awkward or static work postures; (5) direct pressure on nerves and soft tissues; (6) work in cold environments; or (7) whole-body or segmental vibration.[1,2,3] The risk of injury appears to increase as the intensity and duration of exposures to these factors increase and recovery time is reduced.[4] Although personal factors (e.g., age, gender, weight, fitness) may affect an individual's susceptibility to overexertion disorders, studies conducted in high-risk industries show that the risk associated with personal factors is small compared to that associated with occupational exposures.[5]

In all cases, the preferred method for preventing and controlling work-related musculoskeletal disorders (WMSDs) is to design jobs, work stations, tools, and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the worker. Under these conditions, exposures to tasks considered potentially hazardous can be reduced or eliminated.

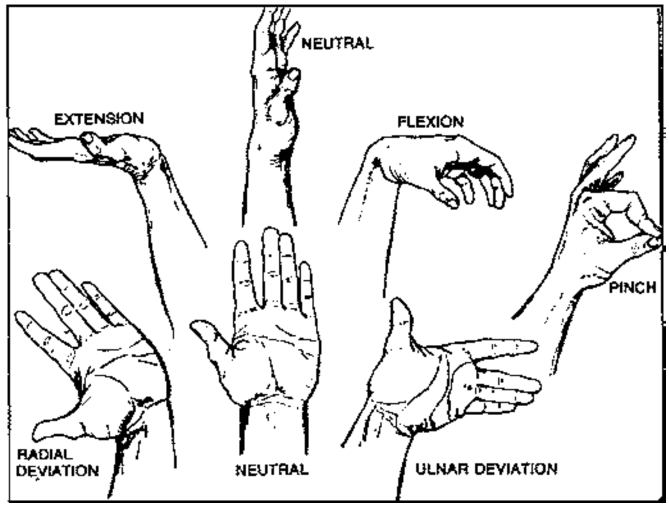
The criteria used to evaluate the ultrasound procedures at the antenatal clinic were workplace and job design criteria found in the ergonomics literature and the biomechanical outputs obtained from the Michigan 3-Dimensional Static Prediction Program.[6]

Results

Ergonomic

Transabdominal. Nine transabdominal ultrasounds were videotaped, averaging 18.5 minutes (range = 3.5–33.8), which included two follow-up exams performed by the perinatologists and took place after the technologists had completed a procedure (such as a Level II exam or a biophysical profile). These are exams used to review and verify the findings of the full procedure and provide the doctor with an opportunity to interpret and explain results to the patient. The follow-ups take less time than the full procedures, which reduced the average time per procedure observed during this evaluation.

The main ergonomic stress factors observed were awkward postures (mainly right shoulder flexion and abduction), sustained static forces, and various types of pinch grips while maneuvering the transducer. Figure 1 shows some common wrist and finger grasp postures. Awkward wrist postures varied because the manner in which the sonographers moved the sensor depended on the size of the patient. In general, if a patient was early in her term and



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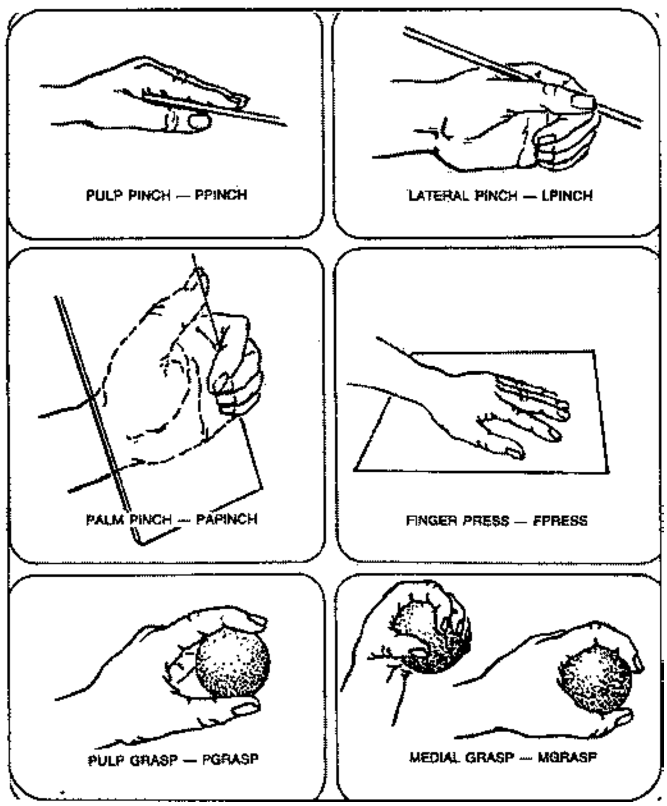

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FIGURE 1
Wrist postures and grip types: a) Neutral and deviated wrist postures; b) Grip type classifications. The grips most used to hold the scan head were the pulp and palm pinch.

the abdomen was fairly small, the ultrasound technologist would maneuver the sensor predominantly with shoulder movements. For patients further along in the pregnancy, with a larger abdomen, sonographers used more wrist flexion and extension to reach the near and far areas of the abdomen.

Because of the position of the equipment, the sonographer had to twist the neck to the left to view the monitor, flex and abduct the left shoulder, and extend the elbow in order to operate the touch screen, the track ball, and the keyboard.

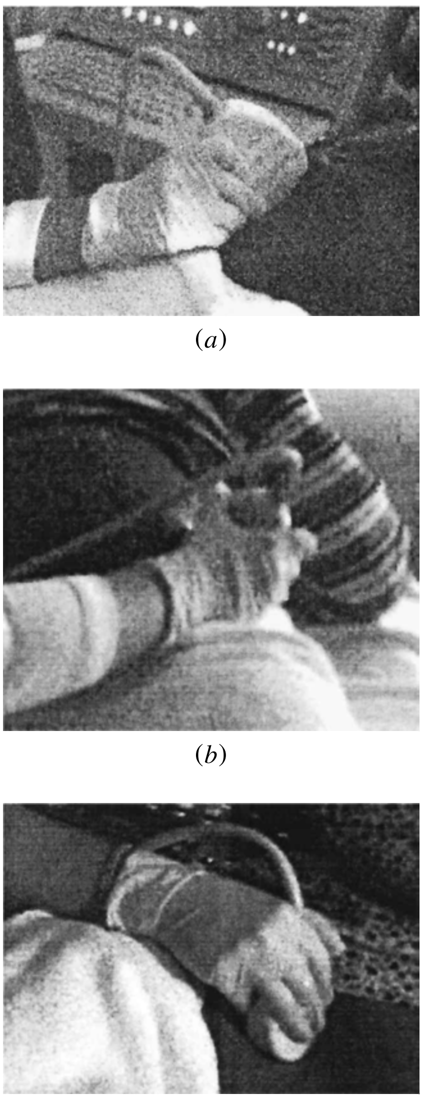

FIGURE 2
The three most commonly seen grips of the scan head: a) Pinch grip on the narrow edge; b) Power grip on the wide edge; c) Fingers over the top.

Several distinct types of grips were used by the sonographers because of the shape of the abdominal transducer. Although the transducer was curved and rounded at the edges, its shape from the top view (which determines the grip type) was rectangular (1 × 3 inches). Consequently, if the sonographer held the sensor along the narrow side, the grip would be a thumb opposing fingertips pinch grip; if the sensor was held along the wide side, the grip would be a power grip. The most common type of grip observed was one in which the sensor was held in the palm of the hand with the thumb on one side (3 ×4 inch dimension) and three or four fingers on the other side. Figure 2 shows the three most commonly seen methods of grasping the scan head.

Video analysis indicated that the configuration of the examination room influenced the type and degree of some of the postures used by the sonographers, particularly shoulder flexion and abduction angles. One of the sonographers was observed performing procedures in rooms having the two types of patient beds. In the room equipped with the 27-inch wide standard bed, shoulder abduction angles approached 70–80° for reaches to the far side of the patient. In the room with the adjustable stretcher that was 24 inches wide, shoulder abduction angles never exceeded 50° and were typically 45° or less (see Figure 3). When the narrow bed was used, the patient was usually positioned at the edge of the bed, which provided support for the sonographer's arm, if it was needed. With the patient lying in the middle of the 27-inch bed, there was clearance between the edge of the bed and the patient, making it more difficult for the sonographer to rest the arm on the patient's leg.

Several of the sonographers were asked to grasp a push/pull force meter as if it were a transducer and demonstrate the average and peak downward forces exerted when obtaining images from a patient. Samples taken from five of the sonographers averaged 4.0 pounds (range = 2.6 to 4.8), and peak forces averaged 8.5 pounds (range = 3.5 to 14.6).

Video analysis also indicated that the transducer was held in the hand during the entire procedure, even when downward forces were not being applied to the patient's abdomen. Sustained static forces lasting 30 seconds were common and some that lasted one minute or more were observed. These types of static exertions were often performed with the elbow unsupported.

Force measurements and shoulder angles were entered into the Michigan 3-Dimensional Model. The results indicated that 90 percent of the female population had the strength to press down 10–15 pounds with a shoulder abduction angle of about 40°, but that only 70 percent had the shoulder strength to exert this amount at 80° abduction. In addition, the movent at the shoulder while force is exerted is 64 percent greater at 80° abduction than at 40° abduction.

Transvaginal

Two transvaginal ultrasounds were observed and videotaped, lasting 1.5 and 1.2 minutes (average = 1.4 minutes). The main ergonomic risk factors associated with the transvaginal procedures are extension and abduction of the shoulder, extension of the wrist, and sustained static grip forces. These postures are a result of the patient's leg between the sonographer's right arm and the equipment, which caused the transducer to be grasped in a power grip. However, because the patient's leg forces the sonographer to elevate the upper arm, the grasp must be made with the wrist in a full or nearly-full extension.

Medical

Not all of the sonographers were at the clinic during the time of the evaluation, and therefore only six surveys were completed. Five of the six respondents reported pain or discomfort in the neck region and in the right shoulder, elbow, and hand/wrist regions. No one reported any left-sided shoulder or arm discomfort.

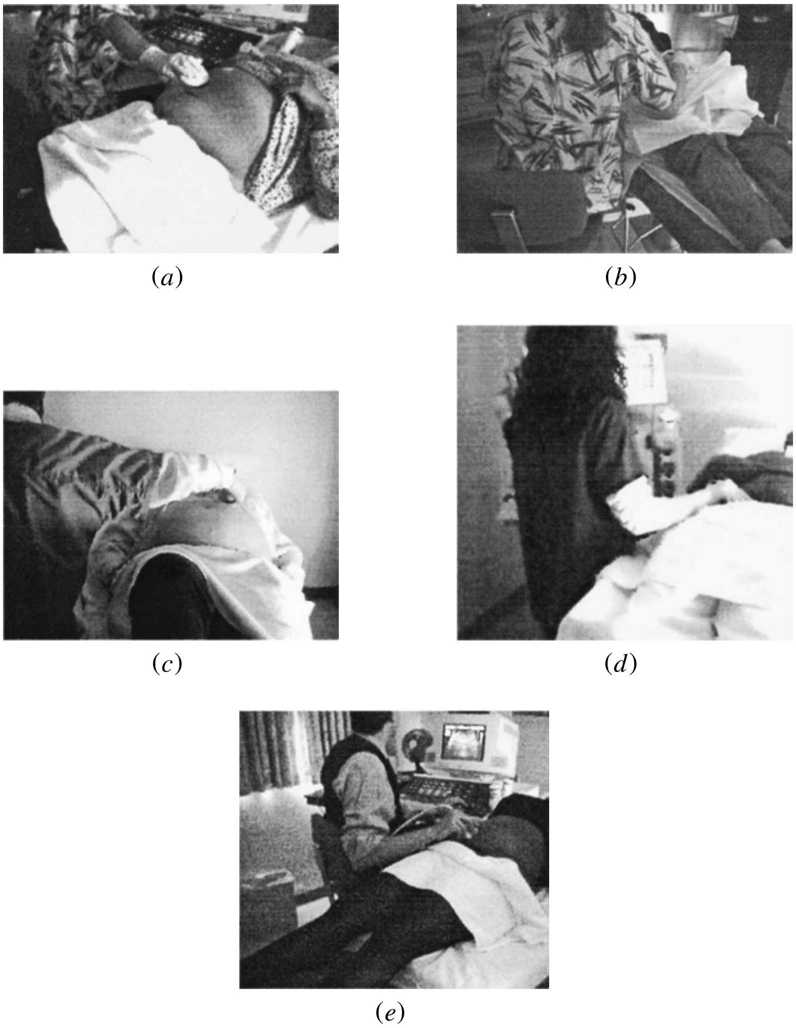

FIGURE 3
Shoulder postures while performing abdominal scans: a) Nearly 90° of shoulder abduction using the standard examination table; b) Example of reduced shoulder abduction using a narrow stretcher with height adjustability; c) Extreme shoulder abduction and long reaching to scan a large patient while sitting; d) Example of neutral shoulder and elbow postures when the sonographer stands; e) Shoulder extension while performing an abdominal scan.

The NIOSH medical assessment was limited because, prior to the site visit, a complete medical examination, including a detailed symptom questionnaire, was conducted on each sonographer under the direction of the clinic medical director. The results were not available at the time of publication.

Discussion

Transabdominal

Musculoskeletal problems experienced by sonographers performing various types of ultrasound examinations have been documented in medical literature.[7,8] Much of the ergonomic information contained in these articles is qualitative and not related to specific job factors. It is likely, however, that the setup of equipment and ultrasound procedures described in the literature is similar to that observed at this facility.

Equipment and Examination Room Components

The key to understanding the problem of ultrasound technologists is recognizing that the job's tasks are comprised of a variety of musculoskeletal injury risk factors, which primarily result from, and are exacerbated by, poor design of workplace components. For example, if the height of the examination table and the chair used by the sonographer could be easily adjusted, the extent of reaching could be minimized; if the sonographer's elbow could be supported when long reaches are unavoidable, the stress to the shoulder and neck muscles could be reduced.

Many of the video sequences analyzed indicated that during long reaches, the sonographer's elbow was just above the patient's leg. A saddle-type pad placed on the patient just below the abdomen, but resting on the examination table, could provide support for the technologist's elbow during long reaches. A recent study evaluating the effects of arm supports on shoulder and arm muscle activity found that the normalized electromyographic (EMG) activity of the deltoid and trapezius muscles of subjects performing simulated assembly tasks was 1.8 to 4.5 times greater when the elbow was unsupported versus supported.[9] These EMG differences were found in subjects performing a task with reach distances across a horizontal table of about 6 inches. Elbow support would likely benefit the sonographers at this facility even more since they were observed to reach as far as 24 inches while recording ultrasound images from patients.

Alternative methods for supporting the elbows of sonographers while they work are in development. Researchers at Simon Fraser University (British Columbia, Canada) are studying the feasibility of using suspended slings to support the elbows of technologists performing ultrasound procedures.[10] The results of these studies are not yet available and the practicality of using slings during ultrasound procedures has not been reported. However, if research findings indicate that slings are effective in reducing muscular fatigue, they may eventually be used to relieve the discomfort of sonographers, particularly by those who perform many procedures per day.

A pad for elbow support would not be as useful when sonograms are performed on a late term patient during which a sonographer's elbow may be several inches to a foot above the patient, but would be effective in many other procedures performed. With late term patients, reach distances would be reduced if the sonographer could stand while scanning the patient, but standing causes a misalignment between the sonographer and the fixed locations of the keyboard and monitor. The ultrasound equipment used at the clinic was clearly designed for a seated sonographer. A 50/50 mix of males and females has an eye height while standing ranging from 56.8 inches (5th percentile) to 67.8 inches (95th percentile).[11] However, the highest monitor height observed at the clinic was only 53 inches. Moreover, it might be cumbersome for the technologist to repeatedly get in and out of a chair, particularly if it were adjusted such that the sonographer's feet were not on the floor. In cases where alternating between sitting and standing during a procedure might be comfortable for the sonographer, a sit/stand stool would be a possible solution. Standing periodically (to reach less) would also minimize the awkward wrist postures that were observed during long reaches with a large patient.

Scan head design. The design of the scan head also can add to the musculoskeletal discomfort of the worker. Regardless of how it is held, the grip is either a pinch along the narrow edge or a power grip across a span that is too large. The shape of the scan head may have been the reason the sonographers alternated among the several grip types observed; apparently no grip was comfortable for very long. The most desirable shape of a handle is round or elliptical, 1.5 inches in diameter.[12] When the sensor is grasped along the thin dimension, either in the middle or at the edge, a 1-inch pinch grip is used. A pinch grip is undesirable because force capability is only 15 to 25 percent that of a power grip and would accelerate the fatigue of a sonographer's muscles.[11] When the power grip is applied along the 3-inch edge, the thin edge of the transducer digs into the thenar area of the thumb and the soft tissue of the proximal digits. The deleterious effects of either of these grips are further intensified by the sustained static forces (downward and to hold the scan head) that are required to obtain some of the ultrasound views. If some conducting gel works its way onto the transducer, the grip forces needed to hold and maneuver it are even greater. Figure 4a shows a close-up of the scan head and a design that is no longer in common use. The older design gave way to the smaller, more compact design because a smaller imaging surface was needed for modern ultrasound procedures. Nonetheless, the older design has more of the desirable design characteristics outlined above than the newer scan head design. The older scan head is wider and longer (to accommodate the length of the hand), and the cord location at the side does not interfere with the hand grip. The older design would be even better if it were more egg-shaped, but it nonetheless allows a grip much more like a power grip than the newer design allows. The best features of each design could be incorporated into one tool by adapting a smaller imaging surface to the older tool or by developing a transducer that has a handle portion "detached" from the "functioning" portion, as is the case with most tools.

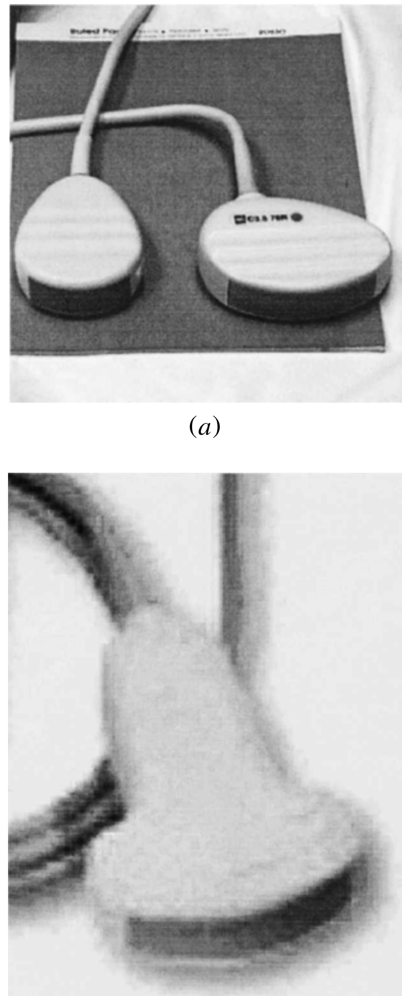

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FIGURE 4
Scan head designs: a) Scan head in current use (left) and an older model (right); b) Newer scan head design featuring a handle allowing a power grip.

Sustained muscular exertions. For light exertions, such as the 4–15 pounds that was demonstrated by the sonographers, ergonomics guidelines suggest that a rest period equal to the length of the sustained muscle exertion should take place before the exertion is repeated.[12] That is, if a sonographer pushes down on the abdomen for a period of 15 seconds to obtain a necessary fetal view, the scan head should be released for 15 seconds to allow for recovery before proceeding with the examination. For exertion times one minute in duration, recovery times of 100 seconds are required. Video analysis indicated that recovery times were never more than a few seconds and the sonographer rarely, if ever, released the transducer.

Biomechanical issues. A moment is defined as a bending force produced at a point of reference (fulcrum) when a force is applied to a perpendicular lever. In the case of the sonographers, the point of reference is the shoulder, the force is the weight of the arm and the downward force applied to the scan head, and the lever is the length of the outstretched arm. This can be simplified by comparing a model that most individuals understand—two children on a seesaw. If one child is further away from the fulcrum than the other, more force (or a heavier child) must be placed on the other side of the fulcrum to keep the seesaw level. For the sonographer to keep an unsupported arm elevated during an examination, the downward force must be counteracted at the shoulder in the form of shoulder muscle contraction. The longer the lever arm, the greater the moment and required muscle forces at the shoulder. If the elbow is supported, or if the hand is held closer to the shoulder, then the counteracting shoulder muscle contractions needed are reduced.

The 3-D biomechanical model was used to estimate strength percentiles and moments about the shoulder while using the transducer. It indicated that musculoskeletal stress could be reduced with more neutral postures of the shoulder and forearm, even though the forces and moments observed were not excessive in magnitude. However, a characteristic of the 3-D biomechanical model, is that it does not take into account repetition. Forces and moments are calculated based on what the model assumes is a single posture. Therefore, if the model indicates a benefit to using more neutral postures during exertions assumed to occur only once, consider the reduction in accumulated muscle fatigue that could be achieved during the repetitive and sustained exertions that occur during an ultrasound examination.

Scanning technique. Musculoskeletal discomfort level during a procedure could also be affected by the manner in which the sonographer approaches the task of performing an ultrasound exam. Many of the technologists performed the procedures with total regard for the patient and little for themselves. They rarely asked the patient to move up or down, to lower her leg to improve their own postures, or to rest their arm on the patient's leg or the edge of the bed. However, the perinatologists were more inclined to adjust the equipment or the patient's position to relieve their postural stress. At one point, one of the doctors moved his chair and ultrasound equipment toward the foot of the bed to reduce shoulder extension and to allow him to rest his forearm on the patient's leg while trying to get a view of the fetus at the base of the patient's abdomen. Improved equipment such as a bed that can be easily moved and adjusted for height and fore-aft position of the patient, would encourage all of the sonographers to make minor adjustments to relieve their pain.

Other issues. The moment at the wrist from the weight of the cord, which is positioned at the top of the transducer is another incidental stressor to sonographers. No measurements were made, but the weight of the thick cord must be opposed by muscle contractions for the entire length of the procedure. One of the sonographers was observed supporting the weight of the cord by wrapping it around her shoulder, and this technique seemed to have merit. All sonographers who have not tried this approach should consider incorporating this minor modification into their technique.

None of the sonographers complained of any left arm pain while using the keyboard or other imaging controls, but most reported discomfort in the neck due to twisting the head to view the monitor positioned to their left. The head postures of the sonographers could be made more neutral with the monitor placed in the normal line of sight, which would be across the bed near the patient's left shoulder.

Transvaginal

Two transvaginal sonograms were observed, each of which was part of a more detailed transabdominal procedure. The typical transvaginal procedure involves fertility studies, where sustained periods of static postures take place while the technologist counts follicles in the uterus. The postures observed during these procedures could not easily be sustained for long periods of time. Sonographers told the NIOSH investigators that during lengthy transvaginal procedures, they often stop the procedure and move the equipment toward the foot of the examination table to improve shoulder and wrist postures. Such a remedial measure is not surprising and suggests that a specific setup for transvaginal sonograms should be sought. Ideally, the sonographer and the ultrasound equipment should be in front of the patient, which would eliminate the need to reach over the patient's leg to control the transducer with the right hand while operating the keyboard and other controls with the left hand.

Conclusions

1. The ultrasound procedures performed at the clinic involve several ergonomic risk factors that contribute to the musculoskeletal pain experienced by the workers.
2. The implementation of improved equipment and components such as adjustable chairs and patient beds would reduce the discomfort experienced by the sonographers.
3. The reaching and muscular force exertions required of the sonographers result in stressful moments and forces on the muscles and joints, and the major ergonomic stress factor is sustained static muscle exertions without adequate recovery between exertions.
4. The use of cushions and pads, as well as procedural changes to minimize reaching with unsupported elbows would reduce the biomechanical load on the workers. This would reduce fatigue and the onset of muscular pain and discomfort.
5. A design for the transabdominal transducer that conforms to generally-accepted ergonomic principles for tool handle design would reduce pain at the hand and wrist of ultrasound technologists.

Recommendations

1. Furnish all examination rooms with an adjustable chair and adjustable bed so that the sonographers can optimize their position with respect to the patient and the ultrasound equipment. The bed should be as narrow as possible to allow the patient to be as

close to the sonographer as possible. The sonographer who was evaluated using the 24-inch-wide bed and the 27-inch-wide examination table was able to reach to the far side of the patient with less shoulder abduction when using the narrower bed. The bed should be height-adjustable, between about 28 and 40 inches, with an electric foot pedal. It should have fore and aft patient position adjustability.

2. Provide elbow support for the sonographers to reduce physical effort and biomechanical loads when reaching to obtain ultrasound images. The support can be as simple as a wedge or a pillow placed between the patient and the sonographer, or more elaborate, for example, a saddle-type cushion placed over the patient and resting on the edges of the bed.
3. Evaluate the use of sit/stand stools to enable sonographers to stand when reaching to the far side of the patient. The success of providing the option to stand would depend on the ease of modifying the keyboard and monitor height to accommodate standing. One approach would be to customize an examination room for each sonographer, or to customize for sonographers of similar size so that height of the monitor and keyboard would be comfortable for sitting and standing. For taller workers, the ultrasound equipment could be placed on an elevated platform to accommodate standing, but the chair and bed could be adjusted to fit the chosen height.
4. Customize an examination room for transvaginal examinations. As noted in the Results and Discussion sections, the placement of the ultrasound equipment at the head of the examination bed forces the sonographer into severely awkward shoulder and wrist positions. The solution is to place the equipment in front of the patient so that the sonographer can operate the keyboard and monitor while manipulating the transducer, with neutral shoulder and wrist postures.
5. Evaluate the possibility of adding an auxiliary monitor, positioned in the line of sight of the sonographer, to eliminate awkward neck postures. An additional remote monitor would allow the keyboard height to be adjusted independently of the monitor, which would simplify raising the entire imaging unit as recommended in the third recommendation. A method of detaching the monitor from the ultrasound equipment to adjust the height without relocation would also improve the work station and benefit the sonographers.
6. Adding an auxiliary handle to, or modify the existing handle of, the transabdominal scan head would allow for a power grip while handling and maneuvering the unit. The handle should be elliptical or round in shape and able to be fashioned without affecting the imaging hardware located inside the scan head. The handle should be 1.5 inches in diameter and at least 4 inches long. A flared edge at the bottom of the handle to support the thenar portion of the hand would be desirable. The texture of the handle should be as slip resistant as possible while adhering to medical standards for cleaning and disinfecting. The cord on the redesigned scan head should be as thin as possible for minimum weight and torque. A modified tool handle meeting the above design criteria that is available with some portable ultrasound units can be seen in Figure 4b. As noted in the Discussion section, the older design shown in Figure 4a is shaped more for a power grip than the newer design, but may need a smaller imaging surface and/or detached handle to accommodate the needs of modern procedures. Whatever the design, the handle should also be equipped with a strap that would enable the sonographer to relax the hand during the procedure without releasing the transducer. Attaching a tool to the hand so that workers can relax their grip between periods of exertion has been shown to be a successful intervention in the meatpacking industry.[13]
7. Develop alternative procedures for conducting ultrasound examinations that emphasize the comfort of the sonographer without compromising the quality of the services performed. This approach would involve sonographers observing and working with each other to establish methods for minimizing stress, which might include wrapping the cord around the shoulder to reduce forces while handling the transducers, asking patients to reposition themselves during a procedure, taking short rest breaks during a procedure to relieve muscle fatigue, and adjusting the position of pillows and cushions that may be used. Many of the suggested methods of administration will be more feasible and acceptable with the implementation of adjustable equipment and remedial aids. Taking rest breaks during a procedure may increase the total time of an examination, but short breaks need not take too much time because sonographers can rest while the sensor is moved about the patient or when the patient is repositioned for a better view. This option assumes the sonographer can release the scan head during these transitional periods.

REFERENCES

1. Armstrong, T.A.; Radwin, R.G.; Hansen, D.J.: Repetitive Trauma Disorders: Job Evaluation and Design. Human Factors 28:325–336 (1986).
2. Gerr, F.; Letz, R.; Landrigan, P.: Upper-Extremity Musculoskeletal Disorders of

Occupational Origin. Annu Rev Publ Health 12:543–66 (1991).

3. Rempel, D.; Harrison, R.; Barnhart, S.: Work-Related Cumulative Trauma Disorders of the Upper Extremity. JAMA 267(6):838–842 (1992).
4. Moore, J.S.; Garg, A.: The Strain Index: A Proposed Method to Analyze Jobs for Risk of Distal Upper Extremity Disorders. Am Ind Hyg Assoc J 56:443–458 (1995).
5. Armstrong, T.J.; Buckle, P.; Fine, L.J.; et al.: A Conceptual Model for Work-Related Neck and Upper-limb Musculoskeletal Disorders. Scand J Work Environ Health 19:73–84 (1993).
6. Users Manual for the Michigan 3-D Strength Prediction Program, Version 3.0, University of Michigan Software: Wolverine Tower, Room 2071, 3003 South State Street, Ann Arbor, MI 48109-1280.
7. Necas, M.: Musculoskeletal Symptomatology and Repetitive Strain Injuries in Diagnostic Medical Sonographers: A Pilot Study in Washington and Oregon. J Diag Med Sonog 12(6):266–273 (1996).
8. Pike, I.; Russo, A.; Berkowitz, J.; et al.: The prevalence of musculoskeletal disorders among diagnostic medical sonographers J Diag Med Sonog 13(5):219–227 (1997).
9. Feng, Y.; Grooten, W.; Wretenberg, P.; et al.: Effects of Arm Support on Shoulder and Arm Muscle Activity During Sedentary Work. Ergonomics 8(40):834–848 (1997).
10. Milner, T.: Personal communication, Department of Kinesiology, Simon Fraser University, British Columbia, Canada.
11. Ayoub, M.M.; LoPresti, P.: The Determination of an Optimum Size Cylindrical Handle by Use of Electromyography. Ergonomics 14(4):509–518 (1971).
12. Rodgers, S.H.: Recovery Time Needs for Repetitive Work. Seminars in Occup Med 2(1) (1987).
13. Armstrong, T.J.; Foulke, J.A.; Joseph, B.S.; et al.: Investigation of Cumulative Trauma Disorders in a Poultry Processing Plant. Am Industr Hyg Assoc J 43:103–116 (1982).

EDITORIAL NOTE: Daniel J. Habes and Sherry Baron, M.D. are with the Division of Surveillance, Hazard Evaluations and Field Studies, NIOSH. More detailed information on this evaluation is contained in Health Hazard Evaluation Report No. 99-0093-2749, available through NIOSH, Hazard Evaluation and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone: 1-800 35-NIOSH; fax: 513-533-8573.