BACK INJURY CONTROL MEASURES FOR MANUAL LIFTING AND SEAT DESIGN

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Introduction

The mining industry has long been associated with a high incidence of low back disorders and pain (Klein et al. 1984, Leigh and Sheetz 1989, Brinckmann et al. 1998). It is believed that the higher incidence of these injuries among miners is the result of high exposures to postural demands, heavy manual work, and exposure to whole-body vibration (WBV). Recent work has indicated that miners involved with heavy lifting (especially in restricted spaces or on uneven ground) or who have been exposed to whole-body vibration in undamped seats experience noticeable changes in their spines that are consistent with degeneration of the intervetebral discs of the spine (Brinckmann et al. 1998). As will be described shortly, there is mounting evidence that disc degeneration plays a large role in the development of low back pain, particularly chronic back pain.

Until fairly recently, medical doctors generally assumed that back pain was the result of muscle strain, ligament pain, or so-called "trigger points" (Bogduk, 1997). However, research supporting these mechanisms of pain has been very scant. When subjected to scientific scrutiny, none of these mechanisms has been shown to relate to back pain in a convincing manner. On the other hand, there are three mechanisms that have been shown to be highly associated with back pain in controlled scientific studies: sacroiliac pain (present in 13% of back pain sufferers) (Maigne et al. 1996), facet joint pain (present in 15 % of back pain sufferers) (Schwarzer et al 1994), and disc disruption and degeneration (present in 39% of chronic back pain sufferers) (Moneta et al. 1994). The latter mechanism, which bears the highest relationship to back pain that has been objectively demonstrated, will be the focus of this section.

Scientists now believe they have a good idea how back pain may develop in cases involving disc disruption and degeneration (Bogduk 1997). As the spine experiences loading during lifting tasks or whole body vibration, the first structure to fail is called the vertebral endplate, which is a structure that attaches the disc of the spine to the vertebral body (Figure 1). The endplate typically experiences a fracture, which the body will attempt to heal by means of scar tissue. Unfortunately, this scar tissue impedes the flow of nutrition to the disc itself (discs are dependent on nutrition from the vertebral bones), and if the supply is reduced sufficiently, the disc will start to degenerate. As this degeneration process proceeds, fissures or tears in the fibers of the disc start to develop. If any of these tears is a grade 3 fissure (Figure 2), an inflammatory response occurs in the disc, which will lead to the well-known sensation of low back pain (Peng 2006).

The best approach to preventing this degenerative process would appear to be minimizing the likelihood of the initial endplate fracture. Endplate fractures can occur in two basic ways. The first is that the endplate's strength may be exceeded by one very large load placed on the spine. This may occur in the case of a fall, an extreme jolt when riding in a vehicle, or during an extremely heavy lift. However, most experts believe that endplate fractures may occur more commonly due to the development of fatigue failure. In this process, a load (perhaps when lifting) will result in a micro-fracture in the endplate or in the bone supporting the endplate. This micro-fracture creates an area of weakness which, with subsequent loading (repeated lifting), will cause the micro-fracture to expand ultimately leading to a full-fledged fracture. Thus, repetitive sub-maximal loading can lead to an injury that is equivalent to an injury experienced in a one-time overload of the tissue strength (Brinckmann et al. 1988, Gallagher et al. 2005).

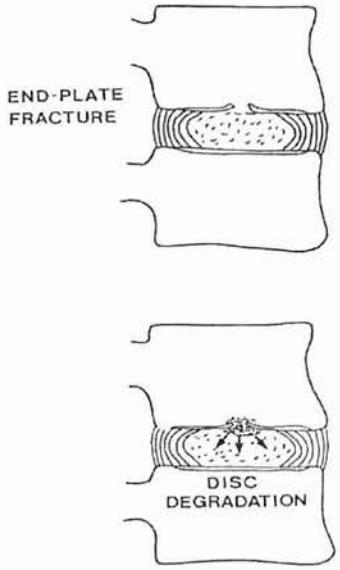

Figure 1. Disc degeneration is thought to be initiated with an endplate fracture, which inhibits disc nutrition leading to disc degeneration (Bogduk 1977).

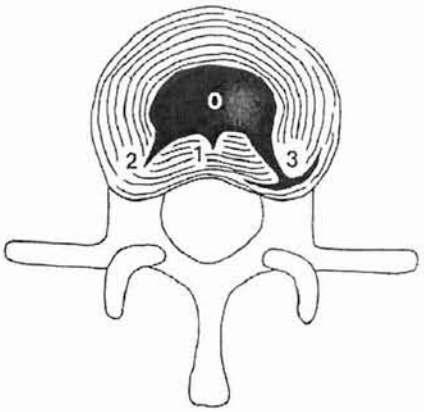

Figure 2. Grade 3 disc fissures have been strongly associated with chronic low back pain (Bogduk 1997).

One important implication of the effect of repetitive loading is that people can be performing tasks that they believe are safe (like lifting a 50-pound bag), because they have done so before without pain, but in reality each lift may be leading to a slight amount of damage. The resulting accumulation of weakness in the spine may lead to an injury

that may result from what seems like a fairly innocuous task (like bending down to pick up a pencil), but which is really the result of damage that has accumulated over time.

Two tasks that are known to place high loads on the spine in a repetitive manner are manual lifting tasks and whole-body vibration exposure as may be experienced when riding in haul trucks or other mining equipment. The purpose of this paper is to describe methods by which the risks of back injury may be reduced.

Controlling Low-Back Risks Associated with Handling Materials

A comprehensive approach is needed to reduce the risks associated with back pain resulting from handling materials. This approach includes factors such as proper layout of facilities and supply handling systems, development and/or use of appropriate equipment or aids, and when manual lifting is necessary, proper design of lifting tasks. While harsh mining environments can sometimes make certain aspects of this approach difficult to implement, there are usually methods that can be used to improve the design of supply handling systems at most mine sites.

Facilities Layout

Transportation of materials is costly in terms of space, machinery, and energy. It does not add value to the object being moved, and exposes workers to numerous hazards. In fact, given that transportation costs for materials typically account for 30-75 percent of the total operating cost, there is a strong economic incentive to improve the efficiency of materials handling systems (Kroemer 1997). However, some may view the reduction of risk to the workers by redesigning, improving, or eliminating transportation barriers to be a more compelling motivation. Fortunately, ergonomic design of material handling systems can benefit both the health of the worker and the bottom line.

Efficient material flow is associated with few transportation moves, whether on the surface or underground. Analysis of current materials handling practices is a critical step in the proper design of both existing and planned facilities. When existing facilities are present, it is often difficult to change the building or the layout; however, improvements in material flow can often be realized. It is much more efficient to design new facilities for the ergonomically best transport than trying to improve a design that is faulty (Kroemer 1997). For this reason, it is vitally important to include an ergonomist in the team that is planning the construction of a new facility.

For existing facilities, generalized checklists have been developed that can help identify problem areas for typical materials-handling operations. Problem areas may include (Kulwiec 1985):

- Crowded operating conditions
- Cluttered entries and supply areas
- Poor housekeeping
- Delays or backtracking in flow of material.
- Obstacles in the flow of materials
- Manual handling of loads weighing more than 45 pounds
- Excessive storage times for materials
- Single items being handled as opposed to unit loads
- Underutilizing materials handling equipment where appropriate
- Excessive time required to retrieve stored parts or supplies
- Multiple handling of the same item

It is often helpful to describe the flow of materials using a diagram or flowchart that shows the sequence and location of materials handling activities, or which represents a listing or table of steps associated with movement of a specific material, respectively (Kirwan and Ainsworth 1992, Gallagher et al. 1990). This type of analysis can be very helpful in identifying unnecessary materials handling activities and other inefficiencies associated with the supply handling system. Obviously, such an analysis has the potential to reduce unnecessary manual materials handling, which will in turn reduce the repetitive loading on the spine that cause low back pain.

Use and/or Development of Mechanical-Assist Devices

Use of Hoists for Materials Handling

One technique that has met with considerable success in the mining environment is the implementation of standard hoist mechanisms (both in the mine and on the surface) to assist with handling timber, track, and other bulky materials, as shown in Figure 3. Several mines have reported that installing hoists at central destination and delivery points can eliminate a significant amount of manual handling of heavy objects (Selan et al. 1997).

Figure 3. Installing hoists at central destination and delivery points can eliminate a significant amount of manual handling.

Development of Specialized Vehicles

Another technique that mines have had great success with is in the development of vehicles to perform specialized functions. In many cases, such vehicles have been built entirely out of salvaged parts and supplies, making these solutions quite cost-effective. Figure 4 shows a materials-handling cart called the "Zipmobile" (named after the miner who developed it). This cart rides on the handrails of the longwall conveyor, and transports supplies along the longwall face. Instead of manually moving supplies beneath the longwall shields, miners can simply load up the cart and pull the supplies down the longwall face (Selan et al., 1997).

Another example of a specialized mining application is the belt car shown in Figure 5. The belt car was made from a recovered supply car, but was modified to allow it to carry a 500 -foot roll of conveyor belt. The modifications consisted of cutting a hole in the bottom of the car (to allow for a larger roll of belt), and installing a pair of stanchions to hold the roll. Using this cart allowed the mine to have a roll of belt mechanically loaded on the car, which could then be driven next to the

tailpiece. This allowed miners to splice 500 feet of belt without having to do any manual handling of the belt other than pulling it off of the roll to perform the splice.

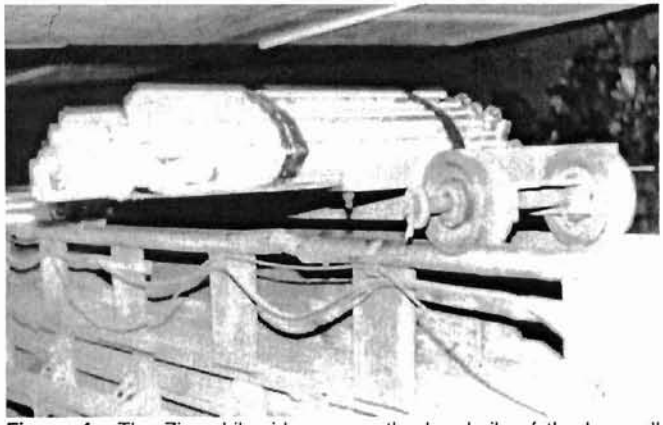

Figure 4. The Zipmobile rides up on the handrails of the longwall conveyor, and facilitates the movement of supplies along the longwall face.

Figure 5. The belt car allows miners to splice 500 feet of belt without having to do any manual handling of the belt other than pulling it off of the roll to perform the splice.

Developing Specialized Mining Tools

One problem that has been identified by many mines is that there are a limited number of tools that are specifically designed for mining tasks. To address this problem, several mines have made efforts to develop in-house tools for specific mining applications. Figure 6 shows an example of such a tool, which is used to help remove conveyor belt rollers. This tool, which has a two-handed handle on one end and a prong which fits into a hole on the belt roller on the other end, provides leverage to facilitate the removal or installation of belt rollers, and prevents having the miner to directly handle the roller (which can get quite hot). Many other tools have been developed for mining applications, largely relying upon innovative ideas developed by the miners familiar with the demands of the jobs they perform everyday (Selan et al. 1997). It should be clear that many opportunities exist for reducing physical demands of mine workers through development, adaptation, or use of mechanical-assist devices in the mining environment.

Design of Lifting Tasks

When manual handling of materials cannot be eliminated through more efficient system design or the use of appropriate mechanical assist devices, it is often possible to reduce the demands associated with manual lifting through appropriate design of lifting tasks. Unfortunately, manual lifting tasks are often considered unavoidable and thus not much thought is put into principles that can significantly decrease the spine loads. However, there are some fairly straightforward design criteria that can dramatically reduce the loads experienced by workers during lifting tasks. The following sections briefly describe some principles that can help this goal.

Figure 6. Use of this specially developed tool provides leverage to remove belt rollers, and prevents having the miner to directly handle the roller (which can get quite hot).

Reduce the Moment

A moment acting about the spine is defined as a force (e.g., the weight of a lifted object) times the distance from the spine to the object's center. This distance has a multiplying effect on the force requirements of lifting a load. Thus, a 45 pound load being held 2 feet away from the body will result in twice the moment about the spine as a the same load held just 1 foot in front of the body. Recent scientific papers have shown that this load moment (the weight of an object multiplied by its distance to the spine) is one of the best predictors of the likelihood that someone will experience a low back injury (Marras et al. 1999). This means that not only can reducing the weight of an object decrease spinal stress, but reducing the horizontal distance to the load being lifted plays a vital role as well. Some ways of reducing the distance to the center of the load include: eliminating physical barriers that prevent the worker from getting close to the load, pulling objects close to the body before lifting, and reducing the size of the object.

Reduce Bending

Recent studies have clearly shown multiple hazards related to bending the trunk forward when lifting. Bending forward creates an additional moment about the low back due to the weight of the torso, which the spine muscles must counteract through increased contraction. Spinal tissues have been found to fail much more quickly when this additional load is imposed (Gallagher et al. 2005). In addition, it has recently been found that when spine ligaments get stretched in sustained or repeated forward bending, the spinal muscles (through a feedback mechanism) actually lose strength and are more prone to spasm (Solomonow et al. 2003). Recovery from the effects of even a brief period of ligament stretching can take 24 hours or more (Solomonow et al. 2003). While restricted spaces in underground mines often limit what can be done to limit forward bending, easier changes are often possible in other areas or facilities. One of the most effective design changes that can be made is to simply get items that must be manually lifted off the floor. Ideally, items should be stored about waist height, and should be stored no lower than knee height and no higher than shoulder height.

Seating Design and Whole-Body Vibration (WBV) Exposure

WBV refers to mechanical energy oscillations that are transferred to the body as a whole, usually through a supporting system such as a seat or platform. Typical exposures in the mining industry include operation of equipment such as haul trucks or front-end loaders in surface operations, and shuttle cars or mantrips in underground mines. A recent review of epidemiologic evidence performed by NIOSH concluded that there is strong evidence of an association between

exposure to WBV and back disorders (Bernard et al. 1997). Clearly, the repeated bouncing and jostling of the body experienced when driving over rough haul roads can be expected to impart significant loads on the lumbar spine, which may accelerate the degenerative changes detailed in previous sections of this paper. In addition, it is known that exposure to WBV can negatively impact worker safety, comfort, working efficiency, and performance (Chaffin and Andersson 1991).

Vibration exposure can influence the human body in many ways determined by factors such as the frequency, amplitude, and duration of exposure. Other influential factors include the direction of vibration input, the mass and location of affected body segments, and the level of fatigue of the individual exposed (Chaffin and Andersson 1991). Interestingly, vibration will affect different parts of the body depending on the frequency since different parts of the body have different resonant frequencies (frequencies at which large oscillations within the structure will occur creating potentially harmful stresses). Figure 7 shows effects of WBV exposure at different vibration frequencies; subjects, exposed to a level of vibration at different frequencies, indicated where they sensed pain or discomfort in their bodies (Magid and Coermann 1960). As can be seen from this Figure, the resonant frequency of the low back is perceived in the low frequency range (10-12 Hz). Furthermore, the resonant frequency of the whole body is 4-5 Hz. It is clear that any input frequency that depicts the external environment at or close to these frequency ranges should be avoided to reduce the likelihood of tissue damage to the spine. For example, a rubber-tired, mine shuttle car has a natural frequency of about 2 Hz. Amplification of vibration will not occur, since the natural frequency of the shuttle car is lower than that of the whole body.

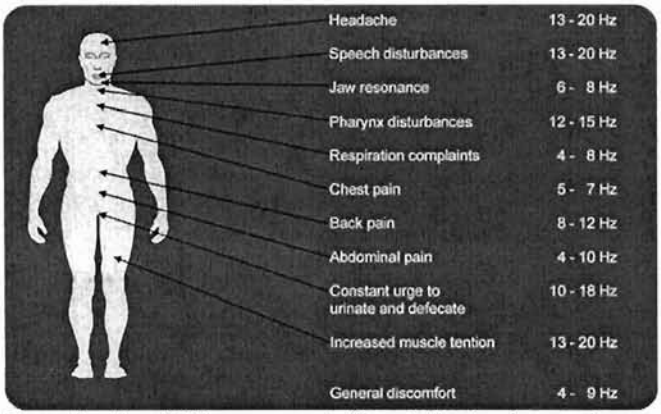

Figure 7. How WBV exposure at different vibration frequencies can affect the human body (Magid and Coermann, 1960).

Probably the best approach to protect against the health effects of whole-body vibration is to isolate the person from the vibrating source with an adequate suspension system, either on the seat or in the vehicle being operated or both (Tong et al. 1999). It should be noted that simply providing a seat cushion to the operator is not necessarily a good solution, since a soft cushion may not protect against, and may even amplify the acceleration (Fraser 1989). However, proper seat design can play a key role in enhancing worker health and safety. Understanding the vibration environment is an important part of designing a safe, comfortable seat.

Seat Design Considerations

Improving Seated Postures in Mining Equipment

Mine workers who operate heavy mining equipment or vehicles may assume different seated postures depending on the design of the vehicle workstation or operator compartment. For example, in underground low-seam coal mines shuttle car operators must assume partially or, in some cases, fully reclining seated work postures due to mine environment, operational, or equipment design constraints. These conditions have risks of worker injury through reduced visibility, increased fatigue from poor seating conditions or awkward postures and reduced work performance.

On the other hand, large surface mining equipment provide the vehicle operator much better opportunity to assume proper seated postures. Vehicles in surface operations are generally thought to provide ample space within a workstation. While this may not always be the case, these vehicles would at least have greater vertical clearance or head space compared to an underground vehicle constrained by a vehicle canopy. The increased vertical clearance can be used to add a seat suspension system that requires limited travel (or stroke) in the vertical direction.

The seated posture for mine vehicle operators, particularly in the context of a vibration environment, is crucial as it defines the initial configuration of the body and that of the spine in particular. Kittusamy and Buchholz (2004) noted two important risk factors for developing MSDs in construction equipment operators are exposure to WBV and non-neutral body postures. Construction equipment are essentially the same as those operating at surface mines with some exceptions. Thus, this would also apply to surface mining equipment operators.

A key objective is to ensure that vehicle operators have an optimum seat that includes energy absorption properties to minimize the risk factors from WBV exposure. Seated posture also affects the worker performance as the upper body muscles and ligaments work to maintain the body in the seat. The premise of work reported by Kazuhito and Hanai (1999) states that in a vibration environment, a small change of posture (like bending the knees or back) changes the sensation of transmitted vibration. These authors suggest that changes in body postures make the body respond differently and hence, can noticeably affect the transmission of vibration energy to the body. The study objectives were to determine the frequency weighting factors for seating postures using seats with backrests, and to determine the effects of the backrest angles relative to WBV exposure. Moreover, they studied how frequency and direction of vibration and vibration transmission through the feet affected comfort for subjects using a seat with rigid cushion and backrest. Contours of equivalent comfort were obtained for subjects by using a discomfort matching procedure. Sensitivities to x-axis back vibration (perpendicular to backrest surface) were significant at 20 and 40 Hz for inclined backrest angles of 20 deg and 40 deg; this was about 1.4 to 1.5 times greater than that on a vertical backrest. Other findings included that subject sensitivities for z-axis vibration taken at the seat cushion were highest at 5 to 20 Hz, and that flexing of the back in the seated posture reduced discomfort at 20Hz.

Reinecke et al. (1987) studied the relationship between pressure distribution, as an index of seating support, and variations in posture of six commercially available office chairs. Other considerations for chair design that could reduce the incidence of low back pain were discussed. These included anthropometric factors, muscle activity, and comfort as well as pressure distribution. The findings included: 1) Pressure distributions of the seat pans were similar on the six chairs studied; 2) Seat pan pressure at the ischial tuberosities increased as the posture changed from 70 deg to 90 deg flexion; 3) In the forward-flexed position, the backrest offered little or no support; and 4) The swivel tilt type of chair appeared to be the best in supporting the lordosis in the inclined position with a concomitant increase in thigh pressure.

A report by Coltman (1983) documented a research effort to increase the effectiveness of energy-absorbing seats through improved design and qualification test criteria. The report contained descriptions of a parametric test program and analyses of seat and occupant response sensitivity to design and test variables. Recommendations for improving military specifications and criteria were also included. Noteworthy conclusions of the study were:

1) measurement of spinal force and moment provides the most reliable means of relating test performance to spinal injury;
2) seat pan acceleration is not a good indicator of test severity or injury potential;
3) placement of the feet can significantly influence seat and occupant response to the occupant load.

In view of the above, important seat features should include adjustability in three directions, adjustability of the suspension system

to accommodate operator differences, and, in particular, adjustability of low back support. When designing a suitable and effective seat, the following guidelines should be considered:

- Minimize vibration transmitted to the body with energy absorbing foam padding and a seat suspension
- Allow for proper spinal alignment to minimize disc pressure with suitable foam padding and adjustable backrest
- Minimize muscle activity associated with maintaining proper postures; the appropriate seat mechanisms, e.g., padding, backrest, and lumbar support will do the work to maintain proper posture instead of the muscles
- Maximize circulation to buttocks, thighs, and knees with proper seat height, seat cushion dimensions, and seat pan angle, SAE (1988)
- Be adjustable for individual differences
- Provide supportive cushioning or padding
- Not interfere with visibility
- Allow for movement of the head or other body parts
- Provide easy access to controls and monitors

Reducing Transmissibility of Vibration

Minimizing transmitted vibration through the seat to the vehicle operator is an important goal of mine health and safety researchers. This is accomplished by suspending first the vehicle, primarily at the wheel units (near the forcing source of the vibration), and secondarily by suspending the seat and workstation. In underground mining vehicles wheel suspensions are not the norm. However, in larger off-road surface mining vehicles this is most often the case. When wheel suspension systems are neither possible nor practical, the next option is isolating or suspending the vehicle seat and, if possible, the operator cab/deck/workstation. Properly designed suspension systems of the vehicle and operator workstation will lessen the required level of isolation at the vehicle seat.

Moreover, the seat design with the most efficient isolating and damping properties should include seat padding and a suspension system with optimized stiffness and damping parameters. This would be accomplished with an active seat suspension designed to provide adaptive optimization through changes in seat stiffness and damping properties as a function of vibration frequency and level of magnitude (Amirouche et al., 1997). In turn, this can result in lower accelerations and power absorption of the human body and thus, lower operator injury and illness risk.

Unique Mining Issues Affecting Seating

Harsh underground mining conditions make it difficult to design an effective and reliable seat with a reasonable life. Because mud and water are often present an underground mine vehicle seat must be made to withstand this punishing environment. Components must be rugged enough to hold up under the large forces and loads that can be generated during operations from the coal, rock, and other heavy equipment. Seat cover material should be used that features a tough vinyl material and when punctured, does not tear. Mayton et al. (2005) described such seat designs using unique viscoelastic foam padding on mid-coal seam and low- coal seam mine shuttle cars. Seats and their components that are installed on the off-road heavy surface mining vehicles should also be designed with heavy duty requirements in mind.

Prevention and Control

Attention to proper roadway maintenance can reduce the WBV load experienced by equipment and haul truck operators, and should be given due consideration in any program to control operator exposures. Moreover, the preferred approach to controlling or preventing WBV exposures and injury risk for the vehicle driver/operator should be engineering controls that emphasize workstation and job design or redesign, Kittusamy (2002). Administrative controls such as switching out mining vehicle operators during breaks and lunch can also limit the WBV exposures that involve awkward work postures. However, controls of this sort should only be considered as an interim solution until better engineering controls are available to minimize injury risk to vehicle operators.

Summary

Low back pain remains a significant and costly problem in the mining industry. Research indicates that disc degeneration resulting from endplate fractures may be a common cause of pain. Prevention of endplate fractures requires reducing the loads experienced by the spine due to lifting and due to exposure to whole-body vibration. Development of more efficient supply-handling systems, innovative approaches to supply-handling problems, and proper design of manual lifting tasks can greatly reduce the risk of back pain, as can attention to proper design of seating.

Engineering controls that emphasize workstation and job design or redesign are first preference for controlling or preventing WBV exposures and injury risk to vehicle drivers/operators. Administrative controls such as switching out mining vehicle operators during breaks and lunch should only be considered as interim solutions until suitable engineering controls are available. Some important guidelines to consider for a vehicle seat are to minimize vibration transmitted to the body with energy absorbing foam padding and a seat suspension; provide adjustable back support, particularly for the low back; and accommodate individual user differences with adjustability. Finally, it may never be possible to completely eliminate back pain in the mining industry; however, there are many steps that can be taken to greatly mitigate the risk.

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