Prevalence and cost of cumulative injuries over two decades of technological advances: a look at underground coal mining in the U.S.

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Abstract

Technological advances in underground coal mining have reduced fatalities but may not have reduced worker exposure to cumulative injury risk factors. The objective of this study was to evaluate the prevalence of cumulative injuries before and after the implementation of technological advances in underground coal mining and to make a general cost estimate for these injuries. A previously published algorithm was utilized to identify cumulative injuries within the Mine Safety Health Administration (MSHA) database for two data sets: 1983-1984 and 2003-2004. For both, the following were determined: the number and percentage of cumulative injuries, the average days lost, the average age at the time of injury, the average years of experience and the general cost estimate by body part. The percentage of cumulative injuries remained largely unchanged (37 percent in the 1983-1984 period and 33 percent in the 2003-2004 period). The average number of lost days due to cumulative injuries increased (36±55 days and 62±82 days, respectively), which may have been due to the increased worker age (~seven years older in the 2003-2004 period), increased length of employment (~seven years longer in the 2003-2004 period) or other factors such as changes in medical practices. Cumulative injuries to the back decreased by 10 percent, while cumulative injuries to the knee increased by 8 percent. The reduction in back injuries may be due to the implementation of assist devices, while the increase in knee injuries may be related to kneeling/crawling in low-seam mines. Cumulative injuries were found to remain a major financial burden on the industry. Recently, National Institute for Occupational Safety and Health (NIOSH) developed tools to assist mining companies with incorporating an ergonomics process into their existing health and safety programs. The participating companies have reported tremendous success. Therefore, it is recommended that ergonomics processes be implemented as a means to systematically identify and address the root causes to cumulative injuries and ultimately reduce costs.

Introduction

In the early 1900s, as many as 3,000 underground coal mine workers died annually. Since then, however, there has been a decreasing trend in mine worker fatalities. In fact, a low of 11 fatalities occurred in 2003 (Mine Safety and Health Administration, 2006). This trend may be due to the fact that technological advances have provided for a safer work environment and have decreased the number of workers required to perform tasks. These technological advances have come in the form of machinery design, control and operation.

As technology advances, it is important to consider the effects of these advances on mine workers, to avoid exposing them to cumulative injury risk factors (CIRFs) such as awkward postures, repetitive motions, jarring and jolting and vibration. During the past two decades, a series of technological advances have greatly changed the working conditions and requirements of mine workers in underground coal mines. These advances include but are not limited to:

- implementing continuous mining machines with fan spray/scrubber systems and remote controls,
- the use of automated roof supports and dual-boom roof bolters and
- mechanization of supply-delivery tasks.

The development of fan spray/scrubber systems and remote control has allowed for increased productivity and has reduced the operator's exposure to whole body vibration. However, with the operator no longer seated on the machine, extended cuts are utilized as the machine is controlled remotely. While the operator's exposure to whole-body vibration may have decreased, the operator handles cables that are longer in length and, thus, more physically demanding (Gallagher et al., 2001). Thus, the operator's overall exposure to CIRFs may not have been reduced.

With the advent of the dual-boom roof bolter, the time spent by the operator tramming and manipulating

Table 1

Average total incurred costs per claim by body part.

National Safety Council Injury Facts	
Part of body	**2004 Edition**
Ankle	$10,358
Arm/shoulder	$16,564
Knee	$16,966
Lower back	$17,738
Upper back	$11,533
Neck	$23,862

the boom is greatly reduced, and the helper installs bolts with one of the boom heads instead of providing supplies to the operator. It is also becoming more common for roof-bolter operators to install secondary supports such as pizza pans, straps and even screening. However, while the tasks performed by the operator and the helper have changed, both are still exposed to CIRFs, such as repetitive motions and awkward postures.

Finally, supply tasks have been mechanized with scoops to reduce the manual tasks performed by the supply person, utility person and laborers. However, there is still a great deal of exposure to CIRFs because the rate at which supplies are needed has increased and the need to manually unload supplies still exists, resulting in lifting, twisting and awkward postures. Other CIRFs were also introduced with the changes in technology, such as jarring and jolting. Furthermore, pinch points were also introduced, which may result in an acute injury that eventually gives way to a cumulative injury because worker capabilities are decreased and the demands on the worker may not be fully adjusted for these limitations while the body heals.

The primary concerns within the mining industry have been reducing fatalities, increasing productivity and decreasing the cost of equipment and replacement parts (McPhee, 2004). While the technological advances in the mining industry may have positively affected workers' tasks and the efficiency of extracting coal, they may not have reduced cumulative injuries. Many jobs still expose mine workers to CIRFs such as awkward postures, exposure to whole body vibration, forceful exertions and repetitive motions (Zhuang and Groce, 1995; Cornelius and Turin, 2001; McPhee, 2004; Steiner et al., 2004).

In the early 1980s, sprains and strains alone were shown to account for approximately 20 percent to 50 percent of all underground mining injuries (Stobbe et al., 1986). Despite the improvements in technology, workers are still exposed to CIRFs throughout their shift. Therefore, the high prevalence of cumulative injuries in underground mining may still exist. Thus, as a means of reducing cumulative injuries it would be necessary to have a drive towards the design of tasks, equipment and tools. However, the National Institute for Occupational Safety and Health's (NIOSH's) interactions with mining companies have indicated that many have not chosen to commit their resources to such an endeavor because a clear cost/benefit had not yet been shown.

The objective of this study was to determine and compare the prevalence of cumulative injuries before and after the implementation of technological advances in underground coal mining and to make a general cost estimate for these injuries. It was hypothesized that a difference in the percentage of cumulative injuries reported in 1983-1984 and 2003-2004 would not be observed because mine workers are still exposed to a host of CIRFs. It was assumed that using two time points separated by 20 years would allow a high likelihood that the data compared was from before and after major technological advances had been in place for an extended period of time.

Methods

While mining companies have rapidly employed some of the technological advances, there are others that the mining companies have been slow to implement. Therefore, data were obtained from periods representing two different decades to ensure that nearly all mine operations now implemented the major technological advances. To increase the sample size and avoid a local minima or maxima in the database, two years were evaluated for both decades instead of just one. Mine Safety and Health Administration (MSHA) injury databases were used for this study. All injuries listed in the MSHA databases for calendar years 1983 and 1984 were combined to form the first data set, which is referred to as the 1983-1984 data set. Similarly, all injuries listed in the MSHA databases for calendar years 2003 and 2004 were combined to form the second data set, which is referred to as the 2003-2004 data set. Both the 1983-1984 and the 2003-2004 data sets were filtered such that only injuries occurring at underground coal operations were considered. The total number of underground coal injuries was then determined for each data set.

To determine the number of cumulative injuries for each data set, a previously reported algorithm was utilized (Battelle Centers for Public Health Research and Evaluation, 1999). This algorithm identifies injuries that were cumulative in nature based on their "nature of injury" code. Cumulative injuries can be attributed to cumulative trauma or can be a reoccurring injury that was initially attributed to an acute trauma. Many injuries caused by an acute trauma result in a recurring injury. Therefore, the methodology utilized in this paper assumes that regardless of whether the injury was initiated by a cumulative trauma or an acute trauma, it is a cumulative injury. Under

Table 2

Breakdown of cumulative injuries by incidence rate, days lost, age and length of employment.

Measurement parameter	**1983-1984**	**2003-2004**
Average days lost for cumulative injuries	36±55	62±82
Average age when suffered cumulative injury	35±9	42±11
Average years of mining experience when suffered cumulative injury	10±6	16±11

this assumption, the following injury codes were isolated: 260 (hernia, rupture), 270 (joint, tendon or muscle inflammation or irritation), 330 (sprain, strains), 370 (multiple injuries) and 400 (unclassified, not determined). Occasionally, injuries to the musculoskeletal system are classified in two other injury codes as well: 380 (occupational diseases, NEC) and 390 (other injury, NEC). However, many of the injuries classified under these two injury codes are not to the musculoskeletal system. Therefore, it was necessary to read the narratives of those injury records to ascertain whether or not the injury was to the musculoskeletal system. Using this algorithm, a total of 8,083 and 3,266 cumulative injuries were identified from the 1983-1984 and 2003-2004 databases, respectively.

For the 1983-1984 and 2003-2004 data sets, the number and percentage of cumulative injuries, with respect to the total number of injuries reported, was determined for underground coal miners. For both sets of data, the days lost due to the injury and the associated incidence rates (normalized to 200,000 hours worked) were then computed (mean±SD). The incidence rate was determined by

$$Incidence\ rate = \frac{\left(Total\ number\ of\ injuries * 200,000\ \text{hrs}\right)}{Total\ hours\ worked} \quad (1)$$

The total hours worked included surface and underground mine workers at underground coal mines, including both bituminous and anthracite operations. For the 1983-1984 and 2003-2004 data sets, the average age of the mine workers who experienced cumulative injuries and their average length of employment in mining were then determined. For both data sets, the cumulative injuries were then further subdivided by the part of body injured. The body parts included in the analyses were the ankle (MSHA data base code: 520), arm/shoulder (MSHA data base codes: 310, 311, 313, 314, 450), knee (MSHA data base code: 512), back (MSHA data base code: 420) and neck (MSHA data base code: 200). The costs of cumulative injuries by body part based on data from the National Safety Council (Itasca, 2004) are presented in Table 1. The manner in which the National Safety Council reported these data has changed over the decades. Therefore, a direct comparison between the 1983-1984 and 2003-2004 data sets is not possible. It should be noted that the cost data provided by the National Safety Council are not specifically for cumulative injuries. Rather, the cost data pertains to all types of injuries to these body parts.

Results

The total number of injuries decreased from 1983-1984 (21,792 total injuries) to 2003-2004 (10,046 total injuries). Cumulative injuries accounted for 8,083 and 3,266 for the 1983-1984 and the 2003-2004 data, respectfully. Thus, despite changes in technology, the percentage of cumulative injuries remained nearly unchanged between the two decades (37 percent and 33 percent, respectively). Additionally, there was only a small decrease in the incidence rate, which dropped from five to four between the two decades, respectively.

When evaluating the average days lost for cumulative injuries, there were 11 injury records in the 1983-1984 data in which this information was unknown. These data were thus excluded from the analysis. For cumulative injuries, it was found that in the 2003-2004 period (62±82 days) the average days lost was higher by 26 days than in the 1983-1984 period (36±55 days). This also corresponded to an increase in the average age of the mine workers that were injured.

Table 3

Breakdown of the number and percentage of injuries by body part for comparison with average costs for injury shown in Table 1.

	1983-1984		2003-2004	
Part of body	**Number**	**percent**	**Number**	**percent**
Ankle	376	5 percent	118	4 percent
Arm/shoulder	355	4 percent	305	9 percent
Knee	752	9 percent	568	17 percent
Back	3,348	41 percent	1,031	31 percent
Neck	475	6 percent	192	6 percent
Other	5,306	66 percent	2,214	68 percent

The average age of the injured mine workers was calculated based on the date of birth entered into the MSHA database. Therefore, occasionally this information is entered incorrectly or not at all. For the 1983-1984 and 2003-2004 data sets, 307 of 8,083 and 64 of 3,266 injury records, respectively, were excluded due to missing information or ages that were likely incorrect (i.e., less than 17 years or greater than 75 years). Using the remaining injury records, it was found that in 2003-2004 the average age of the mine workers that suffered a cumulative injury increased by seven years.

When evaluating the average length of employment of mine workers at the time they suffered a cumulative injury, missing data was encountered for 624 injury records in the 1983-1984 data set and 207 injury records in the 2003-2004 data set. For the remaining injury records, it was observed that mine workers suffering cumulative injuries in 2003-2004 had been employed six more years than those in 1983-1984.

These cumulative injuries were then evaluated with respect to body part (Table 3). It should be noted that, for the 1983-1984 data, five injuries were listed as “unclassified” for body part, while for the 2003-2004 data, two injuries were “unclassified.” Thus, these injury records could not be included in this analysis.

The true cost of cumulative injuries is difficult to determine because the initial indirect costs, such as decreased work rate or capacity, are often unreported until the injury has progressed to the point of needing medical intervention. Thus, it should be noted that the cost data provided by the National Safety Council are not specifically for cumulative injuries but rather for all injuries to the specified body part. Additionally, the manner in which these data are reported has changed over the decades. Therefore, a direct comparison between the 1983-1984 and 2003-2004 data sets was not possible. Thus, the costs of injuries by body part are presented based on the same time point from the National Safety Council (Table 1). For example, in 2003-2004, 569 cumulative injuries to the knee were reported. Thus, one could estimate that this resulted in a cost of $9,636,688, or $16,966 per knee injury. Table 3 demonstrates that back injuries accounted for the largest percentage of cumulative injuries. While there was nearly a 10 percent drop in the percentage cumulative back injuries between the 1983-1984 and 2003-2004 data sets, there was also an increase of 8 percent in the percentage of cumulative injuries to the knee between the two data sets (Table 3).

Discussion

In this study, the prevalence of cumulative injuries across two decades of technological advances was compared and a means to make a general cost estimate for these injuries was provided. Additionally, differences in the incidence rate of injury, age of the miners injured, days lost and length of employment at mining facilities were evaluated to allow for a more detailed comparison.

The data demonstrated that there was a decrease in the *number* of cumulative injuries between the two decades. This may have been due to the decrease in the average number of workers from 103,431 to 44,456 for the 1983-1984 and 2003-2004 periods, respectively (Itasca 2004). However, despite the decrease in the overall number of cumulative injuries, the *percentage* of cumulative injuries remained nearly unchanged (37 percent and 33 percent between 1983-1984 and 2003-2004, respectively). This difference was within the accuracy of the algorithm used to isolate cumulative injuries via the "nature of injury" code (Battelle Centers for Public Health Research and Evaluation, 1999). Therefore, the hypothesis that a difference in the percentage of cumulative injuries reported in the 1983-1984 and 2003-2004 periods would not be observed was supported. For both periods, a large percentage of cumulative injuries were reported, which indicates a need to address these types of injuries. These data compare well with previous studies that have reported sprains and strains or other cumulative injuries to be a major contributor to injury rates (Stobbe et al., 1986).

There was only a small drop in the incidence rate of cumulative injuries, which was within the accuracy of the algorithm used to isolate the cumulative injuries. This indicates that the ratio of cumulative injuries to hours worked has remained largely unchanged as well. Thus, while technological advances may have increased production and decreased fatalities (MSHA), cumulative injuries must still be addressed.

Several other interesting facts were also observed. In 2003-2004, a longer recovery time was required before mine workers could return to work, which was indicated by an increase of 68 percent in lost days compared to the 1983-1984 data. This may have been due to many factors. Previous research has reported that recovery periods for older (>55 years) workers are typically twice as long as those for younger (<35 years) workers (Merchant et al., 2000). Thus, the seven-year increase in the average age of the mine worker injured in 2003-2004 may have been a primary contributor to the increase in lost days. Another contributing factor may have been the longer length of employment for those injured in 2003-2004. While the injury occurred at a later point in the mine worker's career, the cumulative effect of exposure to CIRFs may have been a prolonged recovery period. Additionally, changes in the area of rehabilitation practices may also have been responsible for the increased days. Other confounding factors, such as lifestyle changes, injuries outside the workplace or a combination of several factors, may have also played a role. It should also be noted that there are large individual differences between mine workers, whereby exposure to CIRFs may or may not affect them. Regardless of the root cause (age, exposure, lifestyle, etc.), increased recovery time plays a major role in the cost of cumulative injuries. As the number of lost days increase, costs associated with the injury would also increase due to maintaining replacement workers, workman's compensation and continued rehabilitation and medical evaluations. MSHA provides a calculator that estimates the cost of an accident with lost days at $28,000, but it does not calculate the cost based on the number of lost days themselves.

There was a shift between the percentage of knee and back injuries, with back injuries decreasing while knee injuries increased. However, this change in back and knee injuries may not be directly related. The change in back injuries may be attributed to advances the mining industry has pursued and implemented, such as the use of mechanical-assist devices and educating the mining population regarding back injuries. The increased percentage of knee injuries may be a result of awkward postures, such as kneeling and crawling, as well as uneven surfaces. Any increase in the rate of kneeling, crawling or duck walking may place additional stresses on the knee.

In the future, there may also be a reduction in seam heights across the underground coal mining industry as technology allows for this coal to be extracted more economically (Petersen et al., 2001). This may increase the number of mine workers in low-seam mines and may also increase their exposure to CIRF's associated with knee injuries (e.g., kneeling and crawling). This is a major concern because the cost of knee injuries was nearly identical to that for the back.

At this time, tool and equipment design has been predominately focused on the cost of extracting coal because this has been the primary interest of their clients, the mine companies. Therefore, it is important to inform mine companies about the financial burden associated with equipment designs that do not fully complement the mine worker. If mine companies communicate with equipment manufacturers about the importance of ergonomics in equipment design, future technology improvements will include reductions in operating cost and in worker exposure to CIRFs. In addition to equipment design changes, other factors may also be considered, such as taking out extraneous matter to provide a working height that is larger than the seam height.

The results of this study demonstrate the need to address the cost and prevalence of cumulative injuries. A proactive approach to this problem would be to implement an ergonomics process that would provide a systematic method to identify, prioritize and resolve the root causes of cumulative injuries. Ergonomics processes have already been shown to be successful in industries other than mining (Gjessing et al., 1997). In fact, ergonomics processes have even been implemented at some surface mines with the help of NIOSH personnel, and these are showing signs of success (Steiner et al., 2004; Porter et al., 2007; Torma-Krajewski and Hipes, 2007; Torma-Krajewski and Lehman, 2007). Many companies have been concerned with the resources necessary to implement an ergonomics processes. However, the resources required are often less than initially anticipated because it can frequently be integrated into already existing safety and health programs.

In the current study, only underground coal mining injuries were evaluated. However, for all mining, technological advances were primarily focused on reducing fatalities while increasing production (McPhee, 2004). A limitation to this study was that the data presented were obtained from analyses of the MSHA database, which is an "injury" database. Thus, when mine workers experience the initial symptoms of cumulative injuries they often are not reported. Therefore, the results in this study should be considered a lower bound. Having only injury data also did not allow incidence rates to be age-adjusted, despite the fact that a substantial change in the age distribution of the population was noted between the two data sets evaluated. The data provided to perform a general cost should also be considered a lower bound, because the estimate did not include indirect costs such as those associated with finding a replacement mine worker or training new and existing mine workers. Other indirect costs include reduced efficiency/production, reduced quality, pain and suffering. Additionally, estimates for both decades were generated using cost data for only one time period.

NIOSH intends to continue promoting and assisting mining companies in the implementation of ergonomics processes through Web-based training and "train-the-trainer" guides, which will also provide solutions to common problems. Also, when redesigning equipment to reduce injuries, it is important to understand how mine workers are being injured. Different design characteristics may be warranted if an injury was caused by repetition, excessive force or if it is a recurring injury that initially occurred due to acute trauma. Therefore, in the future, the authors intend to investigate differences in injuries that are cumulative in nature to those that may become cumulative following an initial acute trauma. Additionally, an upcoming NIOSH project and consortium of mining community representatives will begin addressing issues associated with human interface and equipment design.

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Disclaimer

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