Evaluation of Low Back Pain Risks in a Beef Skinning Operation

Biman Das[a] & Arijit K. Sengupta[b]

[a] Department of Industrial Engineering, Dalhousie University, Halifax, NS, Canada

[b] Department of Engineering Technology, New Jersey Institute of Technology, Newark, NJ, USA
Published online: 08 Jan 2015.

PLEASE SCROLL DOWN FOR ARTICLE

Evaluation of Low Back Pain Risks in a Beef Skinning Operation

Biman Das

Department of Industrial Engineering,
Dalhousie University, Halifax, NS, Canada

Arijit K. Sengupta

Department of Engineering Technology,
New Jersey Institute of Technology, Newark, NJ, USA

The low back pain risks in a beef skinning operation at a high stand kill floor workstation was evaluated. The increases in compressive forces at lower back (L5/S1) between normal slump (back angle 25°, measured in the sagittal plane) and severe (45°) and between normal slump and very severe (70°) bent back postures were 387 N or 28% and 616 N or 45%, respectively. The high spine load coupled with high level of repetition can have a high probability of fatigue failure in the spine structural members. Non-neutral back posture for a large portion of the total work time can be a low back pain risk factor. The videotape analysis showed that the times involved during the task performance for the bent back (more than 25°) and severe bent back (more than 45°) were 48.4 and 33.5% of the total cycle time, respectively. The upper limit from OWAS (Ovako Working Posture Analysis System) for bent back posture is 30% of the total cycle time. The bent and twisted back posture (both more than 25°) time was 10.4% compared to OWAS limit of 5%. This indicated that actions are needed in the near future to alleviate the risk of low back pain. Ergonomics redesign of the workstation was recommended for the operation.

low back pain   biomechanical analysis   ergonomics analysis
posture analysis   meat processing

Correspondence and requests for reprints should be sent to Biman Das, Department of Industrial Engineering, Dalhousie University, Halifax, Nova Scotia, Canada, B3J 2X4. E-mail: <Biman.Das@dal.ca>.

1. INTRODUCTION

The nature of tasks performed at the meat processing plants can be a source of occupational musculoskeletal disorders. To deal with such risks, the Ergonomics Program Management Guidelines for Meatpacking Plants (Occupational Safety and Health Administration [OSHA], 1991) have suggested an effective occupational safety and health program. Recently in a meat processing factory, a worker was afflicted with a severe disabling low back pain (LBP) while performing a beef skinning operation at a high stand kill floor workstation. Subsequently, the operator's illness was confirmed by a medical diagnosis conducted by a physician (MD). The worker and his union alleged that the beef skinning line operation caused awkward work posture, resulting in a low back injury to the worker. The company maintained that the LBP was not job related, and denied him worker compensation. The workers' union retained us to evaluate the operation at the workstation and subsequently provide an expert opinion in a court case against the management position on the matter. Our task was to investigate the existing working condition and work method and to determine objectively whether the specific set of tasks performed in that workstation may cause or lead to an occupational back injury.

Occupational back injury is a major concern in industry. It accounts for a substantial worker compensation cost (Waters & Putz-Anderson, 1996). A common manifestation of back injury is LBP. Epidemiological studies show a positive correlation between the exposure to mechanical overload at work and the incidence rate of LBP (Chaffin & Park, 1973). However, except for traumatic and acute cases, the cause of the LBP still remains unclear (Kroemer, Kroemer, & Kroemer-Elbert, 1996). For the manual material handling tasks, it is believed that the source of LBP can be traced back to the repetitive over-exertion at the lower back. This produces micro-trauma at the lower spine structure over a prolonged period of time. The micro-trauma ultimately results in a permanent or temporary damage to the fibro-cartilegnious disks and its surrounding structures and can cause LBP.

An important predictor for such structural failure is the mechanical forces acting at the lumber spine, which depend on the interaction of the worker anthropometry and work characteristics. In the evaluation of workstation and work method, it is important to determine the stresses at lower back due to work performed at different trunk postures. From a biomechanical perspective, the compressive force generated at lower back (L5/S1 level) is believed to be the most significant factor in the development of LBP.

Biomechanical models of lower back with varied level of anatomical details and modeling capabilities have been developed to predict the compressive force in the low back due to external loads. The complex models have dealt with passive force generation and load sharing by muscles and ligaments, asymmetric postures, and inertial effects of dynamic motions. However, at the present state of development of the models, the model outputs are still not reliable enough for judging the absolute acceptability of a work situation, rather they are more suitable for comparing back loading in different work situation (Delleman, Drost, & Huson, 1992). This is because of the inherent difficulty in substantiating the validation of the model outputs and the uncertainties of the living tissue strength values against which the model predictions would be compared. Traditionally, the strength values were based on the failure strength of post mortem spine segments under axial load. Lately, spine segments were tested under cyclic load, and fatigue failure data of spine segments are made available (Brinckmann, Johannleweling, Kilweg, & Biggemann, 1987).

Safe limits of work related to heavy exertion have been well established for lifting and lowering type of manual material handling (Waters & Putz-Anderson, 1996) and push-pull type of exertion (Snook & Ciriello, 1991). But limits for work-related lower back stresses for postural loads are not well defined. Awkward postures are of major concern for workers who are performing repetitive jobs due to the frequency and cumulative effects of exposure. Non-neutral back postures such as flexion, lateral bending, and twisting increase the level of muscle fatigue and intra-discal pressures in the lumbar spine (Andersson, Ortengren, & Herbert, 1977; Chaffin, 1973). Severe trunk postures can elevate the compressive force at low back, even though a load in the hands does not exist or is relatively light in weight (Chaffin & Andersson, 1991). According to the Ergonomics Program Management Guidelines for Meatpacking Plants (OSHA, 1991), an effective occupational safety and health program to address ergonomics hazards in the meatpacking industry includes worksite analysis, hazard prevention and control, medical management, and training and education. An adequate workstation analysis would be expected to identify all risk factors present in each studied job or workstation.

Several whole body posture recording schemes have been developed (Juul-Kristensen, Fallentin, & Ekdahl, 1997) to estimate the postural stress for various types of industrial work. Their effectiveness in quantifying the postural stress has been validated by extensive field studies (Genaidy, Al-Shedi, & Karwowski, 1994). Primarily the posture recording schemes

provide a means to estimate the level of postural stress based on the severity and duration of the work postures. However, most of them do not provide the safe limits of the postural stresses and thus, they are basically useful for comparison of postural stresses before and after modification of a work-site. The Ovako Working Posture Analysis System (OWAS; Karhu, Kansi, & Kourinka, 1977) is a widely used postural recording scheme and has been applied to various types of industries (Pinzke, 1992). A significant relationship between the back postures as defined by OWAS and prevalence in lower back pain has been established by epidemiological analysis (Burdorf, Govaert, & Elders, 1991; Heinsalmi, 1986). The OWAS has a four-grade action classification scale: 1 = normal, no need for action; 2 = strain, actions in the near future; 3 = clear strain, actions as soon as possible; and 4 = hard strain, actions immediately. These limiting level of stresses were derived based on epidemiological field study and expert opinion on the risk of occurrence of occupational musculoskeletal disorders due to typical work postures found in industry.

The main objective of this investigation was to make a worksite analysis to determine whether or not work postures involved in the performance of a beef skinning operation at the high stand kill floor workstation would pose any risks with particular reference to back pain or injury. Specifically, the study was to identify the established standards from the literature regarding the limits of work related stresses at the low back and subsequently to compare them with the specific work related stresses.

2. BEEF SKINNING OPERATION AT A HIGH STAND KILL FLOOR WORKSTATION

The plan view (from top) and elevation view (from front) of the work site with relevant dimensions are presented in Figure 1. The heights of the overhead monorail conveyor, from which the beef were hung, were about 254 and 198 cm from the floors of the upper and lower levels. Due to the difference in hanging method of the beef in the overhead conveyor of the upper and lower levels, the position of the beef in the lower level was found to be 5 to 15 cm below the position of the beef in the upper level. The difference in height depended on the placement of the hanger as well as the size of the beef. Thus, in the lower level, the operator had to bend further for performing the skinning operation. The lower level workstation (right side of Figure 1) was the workstation under investigation.
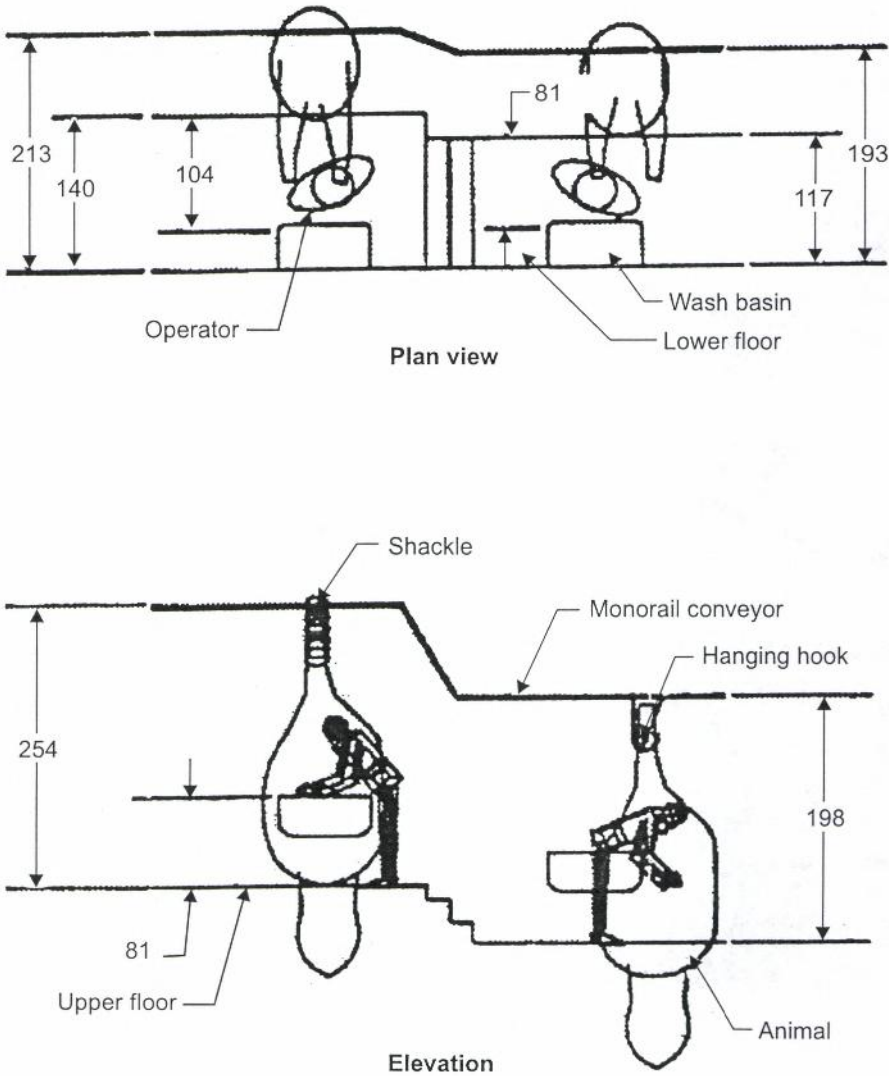
Figure 1. Workplace layout drawing of a beef skinning workstation at a high stand kill floor. All dimensions are in centimeters.

The worker at each station was supposed to (de)skin a pre-assigned area of the beef, while the beef moved continuously with the motorized conveyor. The operations performed at the concerned workstation were skinning a portion of the beef with a straight knife in a normal standing position (Figure 2a) and then bent over past waist level to skin mid and lower part of the beef (Figures 2b, 2c) with an pneumatic circular knife (weighing about 1.5 kg, including a rubber hose). Furthermore, it was observed that

the operator had to pick up the knives from the washbasin in an asymmetric position (Figure 2d). The average task cycle time was 52 s and 450–500 beef were processed in an 8-hr shift. The task performed by the operator was highly repetitive.
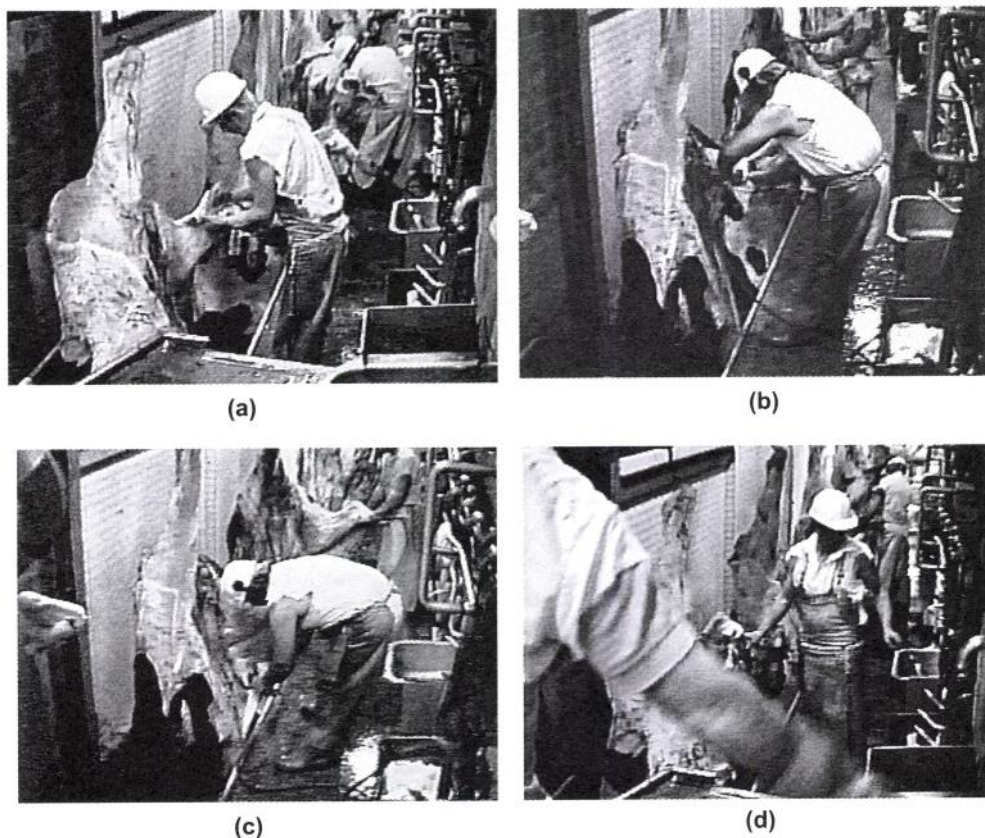
Figure 2. Typical work postures during beef skinning operation: (a) straight/slump, (b) mild flexion, (c) severe flexion, and (d) twist.

3. A BIOMECHANICAL EVALUATION OF LOAD AT LOWER BACK

A biomechanical analysis was performed to determine compressive load at lower back (L5/S1) as a result of performing beef skinning with a pneumatic circular knife. This operation was the most demanding task from the viewpoint of compressive force generated at lower back. The real issue was

whether bending excessively while performing the skinning operation with a pneumatic knife for a long period of time in a work shift (8 hrs), was a potential source of back injury. If that is so, then from an ergonomics viewpoint the workstation was hazardous or unsafe.

A two-dimensional static low back model proposed by Fish (1978) was selected for the analysis because of two reasons: (a) the speed of change from one posture to the next was relatively controlled and slow and hence the dynamic component of the forces would not be significant, and (b) most of the forward bending actions were performed close to the sagittal plane, hence asymmetric loading was not anticipated. Furthermore, it has been shown that in sagittal plane loading situation, the difference in predicted spine load from the simple and complex biomechanical low back models are small compared to the variation in spine load due to change in back postures (Delleman et al., 1992). Thus, the use of this simple biomechanical model was found to be sufficient for computing the spine load for sagittal plane bending conditions. This model considered the upper body as a cantilever, with a combined muscle moment-arm length of 5 cm from the L5/S1 joint.

In this model the effect of intra-abdominal pressure (IAP) was not considered because of the following reasons. Firstly, the available models are not consistent in determining the effect of IAP. Secondly, it has been shown that the benefit from the counterbalancing moment of IAP is largely offset by the abdominal muscle activation necessary to develop the IAP. Using various available IAP estimation approaches, McGill and Norman (1987) found that the reduction in low back compressive force was at the most 3.1% due to IAP, when the abdominal muscle contraction was considered. Unlike heavy lifting, in the beef skinning operation the external load in hand was comparatively light (1.5 kg) and the forward bent postures were maintained over longer periods of time compared to the common lifting tasks. In this kind of holding task, how much IAP (if any) will be generated is uncertain. Due to the small contribution of IAP expected in this situation, it was assumed that the effect of IAP would not be substantial for the purpose of comparing working postures.

3.1. Biomechanical Load at Lower Back (L5/S1 Joint)

For the purpose of this analysis, three typical trunk postures associated with the task were evaluated: (a) normal slump posture (back angle, $\alpha = 25°$, measured in the sagittal plane), (b) severe bent back ($\alpha = 45°$), and (c) very

severe bent back ($\alpha = 70°$). The stick figure models were drawn in Autocad®
(Figure 3). The angles between the adjoining body segments were simulated
on a stick figure model of a 50th percentile male. The segment length,
segment masses, and segment center of mass location values for a 50th
percentile American male was used to compute the compressive force at the
L5/S1 joint (Chaffin & Andersson, 1991).

a) Normal slump posture: b) Severe bent back: c) Very severe bent back:
   Black angle $\alpha = 25°$ Black angle $\alpha = 45°$ Black angle $\alpha = 70°$
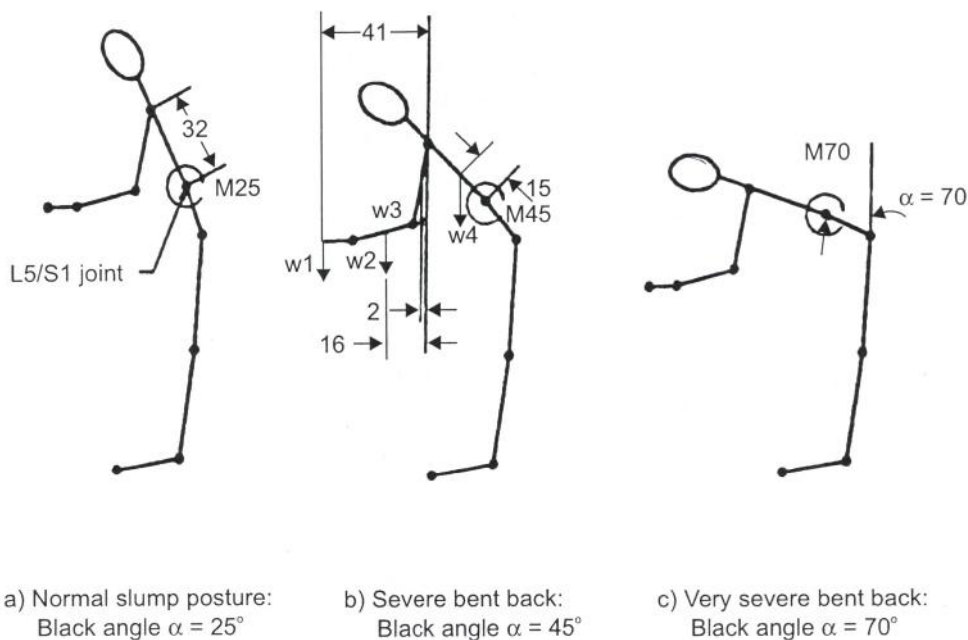
**Figure 3. Postures of a 50th percentile American male at three different back
angles. The position of the upper body segments and center of masses are
shown. All dimensions are in centimeters.**

1. Segment masses for 50th percentile American male:

   Hand + circular knife $W1 = 0.4 \cdot 2 = 1.5 = 2.3$ kg,
   Forearms $W2 = 1.2 \cdot 2 = 2.4$ kg,
   Upper arms $W3 = 2 \cdot 2.1 = 4.2$ kg,
   Head neck and trunk above L5/S1 $W4 = 35.8$ kg.

2. Although the shoulder and elbow angles varied during the skinning
   operation, the typical arm posture observed was the upper arm extended
   approximately 10° and the lower arm flexed about 75° (Figures 2a
   and 2c). To obtain the effect of back flexion explicitly, the posture of the

upper extremities in the model was held constant at the aforementioned angles. The distance of the center of masses of the upper extremity segments from the shoulder joint remained the same for all the three postures. These distances were directly obtained from the Autocad drawing (Figure 3). The values of the moment arm of hand, forearm, and upper arm about the shoulder joint were 41, 16, and 2 cm, respectively. The distance between the shoulder joint and L5/S1 was 32 cm. The distance of the center of mass of head-neck-torso segment from the L5/S1 joint was 15 cm.

3. For a torso angle α, the moment around L5/S1 joint was computed by

$$M_\alpha = (35.8 + 32\sin\alpha) \cdot W1 + (16 + 32\sin\alpha) \cdot W2 + (2 + 32\sin\alpha) \cdot W3 + 15\sin\alpha \cdot W4.$$

Thus,   when $\alpha = 25°$, $M_{25} = 47.9$ N m;
           when $\alpha = 45°$, $M_{45} = 70.8$ N m;
           when $\alpha = 70°$, $M_{70} = 89.6$ N m.

4. Assuming the moment arm of the back muscle to be equal to 5 cm, the reactive muscle tension P_α required to balance the moment

$$P_{25} = M_{25}/0.05 = 958 \text{ N},$$
$$P_{45} = M_{45}/0.05 = 1417 \text{ N},$$
$$P_{70} = M_{70}/0.05 = 1792 \text{ N}.$$

5. Downward force on the L5/S1 due to segment masses =
   $W = W1 + W2 + W3 + W4 = 439$ N.

6. Resultant force R_α on the L5/S1 $= \sqrt{P_\alpha^2 + W^2 + 2P_\alpha W\cos\alpha}$.

Thus,   when $\alpha = 25°$, $R_{25} = 1368$ N;
           when $\alpha = 45°$, $R_{45} = 1755$ N;
           when $\alpha = 70°$, $R_{70} = 1985$ N.

Table 1 presents the summary results and analysis of the compressive forces generated at lower back (L5/S1) at different trunk postures while working with a 1.5-kg load (circular knife) in hand for an average American male. The calculated compressive forces at L5/S1 for normal slump, severe bent and very severe bent back postures were 1368, 1755, and 1985 N, respectively. There was an increase of 387 N or 28% between normal slump and severe bent postures. On the other hand, there was an increase of 617 N

TABLE 1. Compressive Force Generated at Lower Back (L5/S1 Level) in Different Trunk Postures While Working With a 1.5-kg Load in Hand

Trunk Posture	Compressive Force at L5/S1 (N)		% Increase from Normal Slump Posture	
	Our	University of Michigan	Our	University of Michigan
1 Normal slump posture, $\alpha = 25°$	1368	1574	—	—
2 Severe bent posture, $\alpha = 45°$	1755	2164	28	37
3 Extreme bent posture, $\alpha = 70°$	1985	2253	45	43

Notes. α—the angle of trunk flexion; body size and mass data are based on average or 50th percentile American male; calculation is based on two-dimensional biomechanical model of lower back (Fish, 1978) and University of Michigan's 3D strength prediction program.

or 45% between normal slump and very severe bent postures. This analysis showed that the increased bent back posture during beef skinning operation involved significant increase of the spine compressive force.

The largest computed L5/S1 compressive load (1985 N) was about 58% of the safe limit of 3400 N set forth for lifting type of tasks (Chaffin & Andersson, 1991). This limit value was based on the strength of spine segments compiled from several studies, where the spine segments were loaded statically (Jager & Luttmann, 1989). Thus, the applied load appeared to be safe for occasional loading. However, considering the repetitiveness of the present task, fatigue strength of the spine segments should be considered. Based on a laboratory testing of spine segments under cyclic load, Brinckmann et al. (1987) found that for a repetitive load of 50–60% of the static strength, the spine segments had 91% probability of developing fatigue fracture. This probability value was based on a maximum repetition of 5000 cycles. The beef skinning task was highly repetitive, with an average cycle time of 52 s, which amounted to more than 500 repetitions per 8-hr shift. At this rate of repetition, 5000 load cycles could easily be accumulated within 2 weeks of work. Within this short time, any significant repair process of microdamages of the living tissues was not expected (Brinckmann et al., 1987). Hence, the computed spine load from this analysis poses a high risk of progressive fatigue failure within the lumber spine, which in turn could be a precursor of a low back pain.

4. POSTURE ANALYSIS OF HIGH STAND KILL FLOOR WORKSTATION

Keyserling, Punnet, and Fine (1988) pointed out that both mild and severe trunk flexion are associated with increased risk of LBP, if the posture has to be maintained for more than 10% of the work cycle. Other non-neutral back postures, such as twisting, twisting and bending, also constitute a significant risk factor for low back pain (Punnett, Fine, & Keyserling, 1987). This section discusses the computational methods for the temporal pattern of the postural load at the lower back. For the purpose of the posture analysis, videotapes of the high stand kill floor operation were made. Nine work cycles (for two operators) were studied in detail. The operation was broken down in three sequential task elements: (a) slitting buttock, (b) skinning left leg, and (c) skinning thigh and belly. At each second the video was paused and the back posture was noted. The back posture was recorded according to the following classification scheme: (a) straight/slump back ($\alpha < 25°$, measured in the sagittal plane), (b) mild flexed back (bend, $25° < \alpha < 45°$), (c) severe flexed back ($45° > \alpha < 70°$), (d) very severe flexed back ($\alpha > 70°$), (e) twisted back ($\beta > 25°$, rotation about the long axis of the trunk) and (f) flexed and twisted back ($\alpha, \beta > 25°$). The classification of the back postures was adopted form the standard back postures recommended by Keyserling (1986) and Van der Beek, Van Galeen, and Frings-Dresen (1992).

The summary data of posture analysis for the work elements are presented in Table 2. The average cycle time to process or skin one beef was found to be 52.1 s. The average percentage of time spent on the various work elements were (1) slitting buttock, 15.3 s, or 29.4% (of total cycle time), (2) skinning left leg, 17.2 s or 33.0%, and (3) skinning thighs and belly 19.6 s or 37.6%. The data revealed that the third task element—skinning thigh and belly operation—was composed of highest percentage of the non-neutral postures and thus, appeared to be most demanding element of the task. During this work element, the operator had spent only 5.1% of the element time in straight back posture ($\alpha < 25°$). The rest of the 94.9% time of this element was spent in bent and twisted back postures. Out of this 94.9% of the element time, a large portion (53.4%) of time was spent in a very severe bent posture ($\alpha > 70°$). Task element 2—skinning the left leg—also constituted 73.5% of non-neutral postures. Task element 1 had a comparatively small amount of non-neutral postures (21.7%). During this element the operator spent 78.3% of the element time in neutral back posture. For the overall cycle to process one beef, 66.3% of the time was spent in non-neutral postures.

TABLE 2. Average Time (s) Spent at Various Back Postures Over a Work Cycle of a Beef Skinning Operation

No.	Work Elements		Straight Back $\alpha \le 25°$	Flexed $25° < \alpha \le 45°$	Severe Flexed $45° < \alpha \le 70°$	Very Severe Flexed $\alpha > 70°$	Twisted $\beta > 25°$	Bent and Twisted $\alpha, \beta > 25°$	Element Time (s)
1	Slitting buttock	s	12.0	1.1	0.0	0.0	1.0	1.2	15.3
		% time	78.3%	7.2%	0.0%	0.0%	6.5%	8.0%	100%
2	Skinning left leg	s	4.6	5.0	2.6	1.1	1.4	2.6	17.2
		% time	26.5%	29.0%	14.9%	6.4%	8.4%	14.8%	100%
3	Skinning thighs and belly	s	1.0	1.7	3.3	10.4	1.4	1.7	19.6
		% time	5.1%	8.5%	17.0%	53.4%	7.4%	8.5%	100%
	Average time per cycle		17.6	7.8	5.9	11.6	3.9	5.4	52.1
	Percent time in a shift		33.7%	14.9%	11.3%	22.2%	7.4%	10.4%	100%

Notes. α and β denote the angle of trunk flexion and twist, respectively. Number of cycles observed $N = 9$.

According to the OWAS (Pinzke, 1992), the limiting percentage of total time in bent back is 30%. Beyond this limit, it suggests actions in the near future, so that risks related to LBP can be alleviated. From the current posture analysis, the total bent back posture time was (14.9% + 11.3% + 22.2% =) 48.4%, which is well above this limit. Even the total severe bent trunk posture ($\alpha > 45°$) time was (11.3% + 22.2% =) 33.5% of the total cycle time, which exceeded the limit. Consequently from both the counts, the high percentage of time spent in bent back posture and severely bent back posture constituted a high LBP risk factor. The OWAS limit for twisted back posture time is about 25%. As in the present analysis the corresponding value was 7.4%, twisting posture would not pose any risk. However, back bent and twisted limit is 5%. In the present workstation this value was 10.4%. Consequently back bent and twist posture would also constitute an additional potential risk factor for LBP.

5. CONCLUSIONS

Based on the present investigation the following conclusions are made:

1. The biomechanical analysis revealed that the compressive forces at lower back (L5/S1) for normal slump ($\alpha = 25°$), severe ($\alpha = 45°$), and very severe ($\alpha = 70°$) bent back posture were 1368, 1755, and 1985 N, respectively. Thus, there was an increase of 387 N or 28% between normal slump and severe bent postures. An increase of 617 N or 45% between normal slump and very severe bent postures was found.

2. The computed L5/S1 forces did not exceed the safe limit of 3400 N, commonly used for manual lifting task. However, the beef skinning operation was not a lifting task, rather a holding task, which was repeated approximately 500 times daily by a single operator. From the fatigue failure of spine segment data, the calculated load corresponds to a high (91%) probability of fatigue failure of spine segments.

3. The study of the operation based on videotape analysis showed that the operators had to maintain bent back posture 48.4% of time and sever bent back posture 33.5% of time. According to OWAS, allowed bent back posture is 30% of the total cycle, beyond which actions are suggested to reduce bent/severe bent trunk posture in near future. This indicated considerable risk of lower back pain in the present situation.

4. The twisted back posture was 7.4% of the total cycle time. This was within the OWAS limit of about 25%. Consequently no apparent risk of LBP was anticipated.

5. The back bent and twisted posture was 10.4%. The OWAS limit is about 5%. This also indicated actions were needed in the near future to reduce the back bent and twisted posture in the operation.

6. The skinning of beef operation at the high stand kill floor workstation constituted considerable risk of lower back pain due to (a) high level of repetitive spine load, (b) bent/severe bent back posture, and (c) bent and twisted back postures. Consequently, actions were needed to alleviate the situation through ergonomics redesign of workstation, work methods and tool (straight/circular knife).

7. It would be necessary to consider line balancing, job rotation, and work-rest schedule to improve the work situation.

REFERENCES

Andersson, G., Ortengren, R., & Herbert, P. (1977). Quantitative electromyographic studies of back muscle activity related to posture and loading. *Orthopedic Clinic North America, 8,* 85–96.

Brinckmann, P., Johannleweling, N., Kilweg, D., & Biggemann, M. (1987). Fatigue fracture of human lumber vertebrae. *Clinical Biomechanics, 2,* 94–96.

Burdorf, A., Govaert, G. & Elders, L. (1991). Postural load and back pain of workers in manufacturing of prefabricated concrete elements. *Ergonomics, 34*(7), 909–918.

Chaffin, D.B. (1973). Localized muscle fatigue—Definition and measurement. *Journal of Occupational Medicine, 15,* 346–354.

Chaffin, D.B., & Andersson, G.B.J. (1991). *Occupational biomechanics* (2nd ed.). New York, NY, USA: Wiley.

Chaffin, D.B., & Park, K.S. (1973). A longitudinal study of low-back pain as associated with occupational weight lifting factors. *American Industrial Hygiene Association Journal, 34,* 513–525.

Delleman, N.J., Drost, M.R., & Huson, A. (1992). Value of biomechanical macomodels as suitable tools for the prevention of work-related low back problems. *Clinical Biomechanics, 7,* 138–148.

Fish, D.R. (1978). Practical measurement of human postures and forces in lifting. In C.G. Drury (Ed.), *Safety in manual material handling* (pp. 72–77). Cincinnati, OH, USA: National Institute for Occupational Safety and Health.

Jager, M., & Luttmann, A. (1989). Biomechanical analysis and assessment of lumber stress during load lifting using a dynamic 19-segment human model. *Ergonomics, 32*(1), 93–112.

Juul-Kristensen, B., Fallentin, N., & Ekdahl, C. (1997). Criteria for classification of posture in repetitive work by observation methods: A review. *International Journal of Industrial Ergonomics, 19*, 397–411.

Genaidy, A.M., Al-Shedi, A., & Karwowski, W. (1994). Prostural stress analysis in industry. *Applied Ergonomics, 25*(2), 77–87.

Heinsalmi, P. (1986). Method to measure working posture loads at working sites (OWAS). In E.N. Corlett, J. Wilson, & I. Manenica (Eds.), *The ergonomics of working postures. Models, methods and cases* (pp. 100–104). London, UK: Taylor & Francis.

Keyserling, W.M. (1986). Postural analysis of the trunk and shoulders in simulated real time. *Ergonomics, 4*, 569–583.

Keyserling, W.M., Punnet, L., & Fine, L.J. (1988). Trunk posture and back pain: Identification and control of occupational risk factors. *Applied Industrial Hygiene, 3*(3), 87–92.

Karhu, O., Kansi, P., & Kourinka, I. (1977). Correcting working postures in industry: A practical method for analysis. *Applied Ergonomics, 8*(4), 199–201.

Kroemer, K., Kroemer, H., & Kroemer-Elbert, K.E. (1996). Ergonomics: How to design for ease and efficiency. Englewood Cliffs, NJ, USA: Prentice Hall.

McGill, S.M., & Norman, R.W. (1987). Reassessment of the role of intra-abdominal pressure in spinal compression. *Ergonomics, 30*(11), 1565–1588.

Occupational Safety and Health Administration (OSHA). (1991). *Ergonomics program management guidelines for meatpacking plants* (OSHA 3123). Washington, DC, USA: U.S. Department of Labor, Occupational Safety and Health Administration. (Reprinted)

Pinzke, S. (1992). A computerized method of observation used to demonstrate injurious work operations. In M. Mattila & W. Karwowski (Eds.), *Computer applications in ergonomics, Safety and Health* (pp. 359–364). Amsterdam, The Netherlands: Elsevier, North-Holland.

Punnett, L., Fine, L.J., & Keyserling, W.M. (1987). An epidemiologic study of postural risk factors for back disorders in industry. In P. Buckle (Ed.), *Musculoskeletal disorders at work* (p. 74). London, UK: Taylor & Francis.

Snook, S.H., & Ciriello, V.M. (1991). The design of manual material handling tasks: Revised tables of maximum acceptable weights and forces. *Ergonomics, 34*, 1197–1213.

Van der Beek, A.J., Van Galeen, L.C., & Frings-Dresen, M.H.W. (1992). Working postures and activities of lorry drivers: A reliability study of on-site observation and recording on a pocket computer. *Applied Ergonomics, 23*, 331–336.

Waters, T.R., & Putz-Anderson, V. (1996). Manual material handling. In A. Bhattacharya and J.D. McGlothlin (Eds.), *Occupational ergonomics: Theory and applications* (pp. 329–349). New York, NY, USA: Dekker.