Cut-points to prevent low back injury due to force exertion at work

Edgar Ramos Vieira* and Shrawan Kumar

Ergonomics Research Laboratory, Department of Physical Therapy, University of Alberta, Canada

Received 19 April 2005
Accepted 24 June 2005

Abstract. Force exertion is related to low back injuries (LBI). This paper critically reviews the literature concerning cut-points for back force exertion, presents available guidelines in a concise manner, and identifies areas that need further research. The studies reviewed were grouped according to the criteria used to set the cut-point values. Most often cut-points differ than concur. The approach considering physiological, psychophysical, epidemiological, and biomechanical aspects of back force exertion meets the most known criteria and presents the lowest common denominator of instantaneous load for lifting tasks. Further experimental and epidemiological studies in peak load and cumulative exposure are necessary. Compound indices should also be developed for pushing, pulling, and carrying. Future indices should consider electromyographically determined fatigue, differential viscoelastic properties of tissues, aging, and the cross sectional area of back muscles. We hope that this paper contributes to a more systematic appraisal of back force exertion at work.

Keywords: Spine, work-related low back injuries, low back pain, prevention, physical ergonomics, loads, compression, contraction, psychophysical, strength

1. Introduction

This paper reviews the literature on the cut-points for force exertion using back muscles. Cut-points are considered to be the threshold values above which the risk/probability of injury increases significantly. The cut-points reviewed are the limits proposed in the literature for safe back exertion.

The work physical demands (force, postures, movements, repetitions, and duration) can cause and/or aggravate low back injuries [50]. Quantification of the work force demands is needed to better understand the relationship between force exertion and work-related low back injuries. It is necessary to “judge” the amounts of force required by the work. Information on the back force requirements of the work can be used to plan and assess interventions to decrease the number of work-related low back injuries. Thus, cut-points are essential to be able to evaluate the appropriateness of the back force demands of jobs because when the demands exceed the workers capacity low back injuries may occur [64].

The paradigm of this review involves primary prevention of low back injury including the mechanical model of degradation where low back injuries precipitate through the steps of activity, biomechanical stress, temporal loading, tissue strain, and injury [46, 64]. Thus, this paper reviews limits for force exertion using back muscles, accepting that over and cumulative force exertion may cause low back injury precipitation. Due to the multifactorial determination of work-related injuries [64] and the current dispute about the causes of low back injuries, it is pertinent to discuss the issue of reported low back pain vs. actual low back injury because injury causes pain, but injury may not be the only reason for reporting pain. There is some confusion in relation to the role of psychosocial issues in low
back injury causation. The psychosocial issues play a more evident role in the level of disability and return to work after injury [24] than in the injury precipitation itself [46]. According to Feldman [24] “injured workers commonly note that the attitude and manner of their supervisor or employer became far more negative after a reported injury” [24]. One should not assume that the factors that influence return to work are the same as the factors that cause injuries to occur in the first place.

Despite the substantial literature available presenting evidence of the relationship between physical exertion and low back injury, some researchers still question this relationship by arguing that there is not enough evidence and that the problem of “low back pain” is a psychosocial one. One of the arguments used to discount that one of the causes of low back injuries is overexertion resulting in injury by disruption of tissue is that no “injured tissue” can be found in many cases [25, 22]. The current imaging techniques used as diagnostic tools such as radiography or MRI allow for vertebrae and intervertebral discs visualization and injuries or the absence of injuries in these sites do not correlated with reported back pain in many cases. This is the fact that is used to justify that back pain is a psychosocial issue. However, the fact that injury is not found sometimes does not mean that it is not there [93]. Actually, it shows that we need new diagnostic tools or we need to adapt the existing ones so that we can assess potentially injured tissues such as ligaments and muscles. Even for other types of work-related musculoskeletal disorders such as wrist tendinitis, the diagnosis is based on clinical findings instead of histological evidence due to the invasiveness of the procedures that could actually “prove” the presence of injury [73]. Imaging is usually not useful and unnecessary for low back injury diagnosis [21, 76]. Besides, the presence of injury is supported by the strong evidence (based on review of systematic reviews) for the use of nonsteroidal anti-inflammatory drugs and muscle relaxants for reducing low back injury in acute phase [84], however it may be partially due to placebo effect. In spite of the controversy, the literature supports that force exertion using the back muscles (e.g. lifting heavy weights) can result in the precipitation of low back injuries. The results of several studies supporting this view are summarized and critically reviewed in this paper. In addition, prolonged sitting, vibration, bending, and twisting were also found to be risk factors for low back injuries [28, 59, 75].

Work-related low back injury is common place and represents the most costly musculoskeletal disorder and a lot of suffering [3, 9, 57]. It is estimated that between 60 and 80% of the adult population will present at least one episode of low back pain during their active work life. In 1988, seven million Americans suffered from low back pain [30]. In 1993 more than five million were out of work due to lumbar disorders alone. Of these, two million were permanently injured, and for each ten adults at least one presented chronic back pain associated with physical incapacities, such as difficulties to walk, stand upright, sit and stand up. Chronic pain is the most expensive problem for the worker compensation system of the US ($14 billion/year). A single episode of back injury causes at least 14 lost days [19]. Between 1991 and 2001, 24.2% of all injuries and illnesses in the US resulting in days away from work were due to back problems [9]. In 2000, from 11 to 13 million people developed low back pain, and about $100 billion were spent on this problem only in the US According to the US Bureau of Labor Statistics, the incidence rate for work-related low back injury involving days away from work per 10,000 full-time workers in 2001 was 20.2. Sixty-five percent of all reported cases of low back injury in 2001 were caused by overexertion; 60% occurred in lifting [9]. In addition, 40% of these cases occurred in operators, fabricators, and industry laborers, the main occupational groups reporting low back injury. In 2001, 26.8% (N = 10,178) of all claims accepted by the Workers’ Compensation Board of Alberta (WCBA) were related to low back injuries. In 2002, this value was 26.1% (N = 9,816) with the back being the main injured body part [3]. Seventy-five percent of these low back injuries were sprains, strains, and tears. Approximately 70% of the sprains, strains, and tears resulted from overexertion while pulling, pushing, lifting, carrying, twisting, climbing, tripping, and reaching [3]. As commented in Kumar’s Annual Ergonomics Society Lecture in 2003 [65], based on the National Health Interview Survey it was estimated that in the US, considering only the people who had worked in the previous year, 22.4 million had back pain. For the back pain group, 56% were males and 44% were females. The male workers with highest risk (prevalence ratio > 2) were construction employees, carpenters, and industrial truck and tractor operators; while the highest risk female workers were nurses, orderlies, attendants, maids, janitors, and cleaners [51].

Since the industrial revolution, many risks to the development and aggravation of low back injuries have been identified and controlled to some extent. A common strategy used by industry has been the mechanization of production. Automation may help to alleviate
the problem somewhat, but it does not solve it. In addition, it contributes to the social problem of unemployment. Another limitation is that in semi-automated systems the task becomes more repetitive in nature and the workers feel “robotized” due to the fragmentation of the task increasing the risk of low back injuries [12, 26]. Furthermore, many industrial and non-industrial work activities inevitably require handling [45]. Thus, to improve the control of work-related low back injuries, the complexity of the interaction between man and his work has to be understood. By doing so, it might be possible to determine safe forces in which work can be done with relatively low risk of low back injury. Thus, it is possible to better control for work-related low back injuries by ensuring safe exposures. Westgaard and Winkel [92] defined mechanical exposure as “mechanical forces generated to meet work demands, considering level, repetitiveness and duration” [92]. Kumar [66] defined overexertion as “a physical activity in which the level of effort exceeds normal physiological and mechanical (physical) tolerance limits” [66].

The establishment of cut-points for back force exertion during work is difficult due to the great variability of human capabilities and tissue tolerances. Also, the experimental complexity involved in the determination of these limits has imposed restrictions to the current extent of our knowledge in this area. The common approaches used to determine these cut-points employ physiological, biomechanical, and psychophysical methods. The physiological approach includes measures of variables such as the energy cost of the activities, the oxygen consumption during the job, and the electromyographic activity of the back muscles involved in the work task. The biomechanical approach includes direct measure of forces exerted by the back muscles to accomplish a job using load cells and/or dynamometers, estimations of compression and shear forces on different back tissues and joints using biomechanical models, measures of joint position (posture) and movement (including range, velocity and acceleration) using different equipment such as electrogoniometers and video-recording systems, and measures of back tissues tolerance to stress (mainly in vitro experimentation). Finally, the psychophysical approach involves worker/subject definition of acceptable levels of activity. In this case, as stated in Snook and Ciriello [78], workers were instructed to “work as hard as you can without straining yourself, or without becoming unusually tired, weakened, overheated, or out of breath” [78]. The psychophysical approach is used to define activity levels that are acceptable to different percentages of the population (i.e. 10, 25, 50, 75, and 90% of the female and male population).

Despite the availability of cut-points for back force exertion at work, there are no gold standards and each of the proposed cut-points have weaknesses according to the assumptions made in establishing each of the proposed values. Also, the available recommendations are not presented concisely in the scientific literature making the decision making process difficult. For these reasons, the objective of this paper was three fold – (I) to critically review the scientific literature concerning the cut-points for force exertion using the back during work; (II) to present the available guidelines in a concise manner; and (III) to identify areas that need further research.

2. Methods

This review included articles that met the inclusion criteria stated below. Papers published in the English language before 2004 including different combinations of the following words in the title, abstract, or keywords were searched in the PubMed (Medline), Scirus, and Science Direct (Elsevier Science) databases – “force”, “work”, “low back”, “exertion”, “cut-points”, “threshold values”, “limits”, and “tissue tolerance”. To be included, the articles had to address back force exertion cut-points, include a classification of the cut-point (e.g. increased risk of low back injury if exertion is above the cut-point), use quantitative measures (load cell, dynamometer, electromyography, biomechanical models), present objective results (e.g. odds ratio, relative risk, injury prevalence), and not be based only on expert opinion. Relevant papers in the reference lists of those articles selected as well as review papers connecting the results of articles meeting the established criteria and pieces of information from relevant textbooks were also included. The studies reviewed were grouped based on the criteria used to set the cut-point values in “weight and distance of the load from the body”, “percentage of maximum voluntary contraction used”, “acceptable loads based in worker opinion”, “weight and number of repetitions”, “intra-abdominal pressure”, “spinal compression forces”, and “compound index”. "compound index". 
3. Results

Different approaches have been used to propose cut-points for back force exertion. Table 1 presents a summary of the studies reviewed by criteria used including references, proposed cut-point, classification of the cut-point, and possible problems.

3.1. Weight and distance of the load from the body

Chaffin and Park [10] conducted a one-year longitudinal study about the relationship between low back injury and occupational lifting [10]. Their study included 411 subjects from 103 jobs. They suggested that not only the load has to be taken into account but also the distance between the load and the body. Based on the results, they stated that there is increased risk of low back injuries when workers lift more than 35 pounds (approximately 16 Kg). If the horizontal distance of the load is more than 20 inches (approximately 51 cm) from the ankle, lifting even lower loads (more than 20 pounds, approximately 9 Kg) represents increased risk of low back injury. The authors normalized the data by dividing the maximum weight lifted by the maximum lifting capacity of a “large/strong man”. The authors called this method “lifting strength rating (LSR)”. Based on their findings, they stated that when the load is above 20% of the maximum lifting capacity of a “large/strong man” (LSR > 0.2) the worker is at increased risk of low back injury. According to the authors, 0.2 LSR weight is close to what 95% of women are capable of lifting close to the body (see Section 3.3 “Acceptable Loads Based on Worker Opinion”). The limitation of this study is that the considerations are made for lifting with both hands in the sagittal plane. This ideal situation is not always present in the work environment. This way, lower values may represent risk to the musculoskeletal system when the conditions are different from those studied (during asymmetric lifting for example). Actually, Warwick et al. [91] has shown a reduction from 38 to 50% of the maximum voluntary strength for asymmetric lifting in comparison with sagittal plane lifting [91]. Weight and distance of the load from the body is a parameter frequently used to assess workload. These parameters are directly related to the resulting spinal compression forces. They are used on the biomechanical models and compound indexes, and are further discussed in Sections 3.6 and 3.7 of this paper.

3.2. Percentage of maximum voluntary contraction used

Localized fatigue develops with uninterrupted contraction and is associated with localized muscle pain. A study by Lindstrom et al. [39] presented a method for evaluation of muscle fatigue by power spectrum analysis of electromyographic signals [39]. The results showed that during contractions from 15 to 20% of the maximum voluntary contraction (MVC) blood flow starts to be impaired; at 60% of MVC blood flow is totally blocked. Decreased or interrupted blood flow is related to muscular fatigue due to intracellular acidosis (accumulation of metabolites) and/or lack of energy (lack of substrate supply). Even low levels of muscular contraction can cause fatigue by decreasing potassium concentration in the muscle resulting in muscle fibers’ excitability alteration. For example, Sjogaard [80] and Sjogaard et al. [80] found a lower membrane potential after 1 h contraction at 5% of MVC even though the blood flow was not affected; there was a 12% reduction on knee-extensors MVC [79,80]. Thus, independently of the level of contraction, rest periods are necessary for recovery since no contraction can be maintained continuously. Safe levels of continuous low level isometric contractions need to be determined to establish guidelines for work-rest schedules.

3.3. Acceptable loads based on worker opinion

Snook and Ciriello [78] published several tables presenting psychophysically determined maximum acceptable weights and forces for lifting, lowering, pushing, pulling, and carrying tasks [78]. The tasks varied in frequency, distance, height, and duration. The objects varied in size and design (boxes with and without handles). Due to the extensive data presented by the authors the entire list of recommendations is not included in this paper; for additional information reefer directly to the paper [78]. The study by Snook and Ciriello [78] was used to generate the psychophysical criteria used in the NIOSH 1991 lifting equation to establish 23 Kg as the maximum recommended weight in “optimal conditions” (occasional lifting in the sagittal plane, with good couplings, and vertical displacement of less than 25 cm). This is the revised limit proposed by NIOSH, the initial limit was much higher (40 Kg) [61]. This cut-point (23 Kg) is based on psychophysical determination of acceptable loads to be lifted for different durations and frequencies. The proposed cut-point causes 3400 N spinal compression, requires 3.5 Kcal per minute en-
## Table 1
Summary of the studies including cut-points for back force exertion

<table>
<thead>
<tr>
<th>Criteria</th>
<th>References</th>
<th>Cut-point(s)</th>
<th>Classification(s)</th>
<th>Problem(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight and distance of the load from the body</td>
<td>Chaffin and Park [10]</td>
<td>Weight $&gt; 16$ Kg; Weight $&gt; 9$ Kg if horizontal distance $&gt; 51$ cm; Max. weight/max. capacity of “strong man” ratio $&gt; 0.2$</td>
<td>Increased risk of low back injuries (LBI). Recommendations for lifting, based on incidence rates ($n = 411$)</td>
<td>Only applicable for sagittal lifting. The lifting strength rating uses a pre-defined maximum capacity not considering workers variability and duration of force exertion.</td>
</tr>
<tr>
<td>Percentage of maximum voluntary contraction (MVC) used</td>
<td>Lindstrom et al. [39]</td>
<td>Contraction $\geq 15 %$ of MVC</td>
<td>Decrease in blood flow</td>
<td>The values depend on the musculature evaluated (percentage of different type of muscle fibers)</td>
</tr>
<tr>
<td></td>
<td>Sjøgaard [80] and Sjøgaard et al. [79]</td>
<td>Contraction $\geq 60%$ of MVC for 1 h</td>
<td>Blocked blood flow, fatigue</td>
<td></td>
</tr>
<tr>
<td>Acceptable loads based in worker opinion</td>
<td>Snook and Ciriello [78]</td>
<td>Weight $\geq$ acceptable to 75% of female and 99% of male workers</td>
<td>Increased risk of lifting-related LBI</td>
<td>Tolerance levels of workers do not represent a limit for injury precipitation</td>
</tr>
<tr>
<td></td>
<td>Ahlborg et al. [1]</td>
<td>Weight $\geq 12$ Kg for $&gt; 50$ times/week</td>
<td>Increased risk of pre-term birth (less than 37 weeks of gestation). Prospective study of 3906 pregnant workers Odds Ratio (OR) of 1.7</td>
<td>The samples back strength level may be higher than same working populations</td>
</tr>
<tr>
<td>Weight and number of repetitions</td>
<td>Punnett et al. [75]</td>
<td>Weight $\geq 4.54$ Kg when repetition $&gt; 1$ time/min. during the entire workday</td>
<td>Increased risk of LBI OR 2.2</td>
<td></td>
</tr>
<tr>
<td>Intra-abdominal pressure (IAP)</td>
<td>Davis and Stubbs [15–17]</td>
<td>$\geq 90$ mmHg</td>
<td>Increased risk of LBI</td>
<td>The effects of increased IAP are controversial</td>
</tr>
<tr>
<td>Spinal compression force</td>
<td>Evans and Lissner [23] and Sonoda [36]</td>
<td>$3400$ N</td>
<td>Microfractures of the vertebral cartilage endplates of subjects $\geq 60$ years old</td>
<td>The values are means with high standard deviations. Values from cadavers, living structures might differ. Do not consider cumulative effect. Based on axial compression only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$6700$ N</td>
<td>Same for subjects $&lt; 40$ years old</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chaffin, Park [10]</td>
<td>$2500$ N $4500$ N</td>
<td>5% LBI incidence rates $10%$ LBI incidence rates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIOSH [55]</td>
<td>$3400$ N</td>
<td>Action limit (AL) for compression at L5/S1. If $&gt; AL$, increased risk of LBI</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$6700$ N</td>
<td>Maximum permissible limit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hutton, Adams [34]</td>
<td>$10249$ N</td>
<td>Ultimate compressive axial force of intervertebral discs of cadavers of males between 22 and 46 years old</td>
<td>The values are means with high standard deviations. Values from cadavers, living structures might differ. Do not consider cumulative effect. Based on axial compression only.</td>
</tr>
</tbody>
</table>
Table 1, continued

<table>
<thead>
<tr>
<th>Criteria</th>
<th>References</th>
<th>Cut-point(s)</th>
<th>Classification(s)</th>
<th>Problem(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal compression force</td>
<td>Adams, Hutton [34]</td>
<td>5400 N</td>
<td>&gt;40% of the intervertebral disks prolapsed. Flexed spines: simulated by wedging vertebral bodies</td>
<td></td>
</tr>
<tr>
<td>(continued)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adams, Hutton [34]</td>
<td>3800 N</td>
<td>Intervertebral disks trabecular fracture. Repetitive loading of simulated flexed spines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Herrin et al. [32]</td>
<td>$\geq 4500$ N and $&lt;6800$ N</td>
<td>LBI IR 1.5 higher than when compression $&lt;4500$ N</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brinckmann et al. [5], Biggemann et al. [6], and Brinckmann et al. [7,8]</td>
<td>Loads $\sim60%$ of ultimate compressive strength (UCS); 5000x; over 6 h; Loads $\sim70%$/UCS; 500x; 30' Loads $\sim75$/UCS; 10x; 40'</td>
<td>Increased risk of fracture $&gt;90%$ of lumbar vertebrae fracture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jager and Luttmann [36]</td>
<td>4400 N</td>
<td>Axial compression limit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Norman et al. [58]</td>
<td>3423 N</td>
<td>Increased risk of LBI: OR1.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTIS [52] and Waters et al. [89]</td>
<td>Lifting index $&gt;1$</td>
<td>Increased risk of LBI “for some workers”</td>
<td>There are several restrictions (e.g. it requires use of both hands, specific ranges of motion, velocity, etc) and it is limited to lifting only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lifting index $&gt;3$</td>
<td>Elevated risk of LBI “for many workers”</td>
<td></td>
</tr>
</tbody>
</table>

Psychophysical studies also have shown differences in maximal acceptable weight for non-sagittal lifting. Ljungberg et al. [41] reported that for lateral transfer (i.e. horizontal lifting from one table to another) subjects chose weights of only half of the load compared to the weight reported in other studies as chosen for lifting in the sagittal plane [41]. In addition, Garg and Badger [29] conducted another psychophysical study about acceptable weights and isometric strengths during symmetric ($0^\circ$ in relation to the sagittal plane) and asymmetric lifting ($30^\circ$, $60^\circ$, and $90^\circ$) at a frequency of one lift every five minutes [29]. Both the maximum acceptable weights and the maximum isometric strength decreased by increasing the degree of asymmetry ($p < 0.01$). The decreases in the maximum acceptable weights (MAW) and in the maximum isometric strengths (MIS) in relation to the values obtained for lifting in the sagittal plane (symmetric lifting, $0^\circ$) were presented. There was 23% reduction in MAW for asymmetric lifting at $90^\circ$, 15% at $60^\circ$, and 7% at $30^\circ$ planes respectively. In relation to the MIS, there was 31% decrease at $90^\circ$, 21% at $60^\circ$, and 12% at $30^\circ$ planes respectively. The authors suggested the following equation for the calculation of the maximum acceptable weight:

$$MAW = 18.1 + (0.528MIS)$$
Where: $\text{MAW} = \text{maximum acceptable weight in Kg}$; $\text{MIS} = \text{maximum isometric strength (adapted from Garg and Badger [29])}$.

These authors found that the percentage decrease in MIS was higher than the percentage decrease in MAW for the three positions ($30^\circ$, $60^\circ$, and $90^\circ$). This fact further supports the previously discussed issue that the tolerance levels of workers may not represent a limit for injury precipitation since the percentage of the maximum isometric strength is increasing without being accounted for or noticed by the workers. One of the limitations of this calculation is that the formula is based on a sample of 13 young male subjects (age range from 21 to 35 years old), with a determination coefficient of 0.62 and a standard error of 5.6 Kg. The average maximum acceptable weight was approximately 38 Kg which is 65% higher than the maximum acceptable weight suggested by the NIOSH 1991 lifting equation (23 Kg).

3.4. Weight and number of repetitions

In a 3-year prospective cohort study including 861 workers, physical load was directly assessed, back exertion including force and posture was critical to the development and aggravation of work-related back injuries [33]. For the sub-group of 724 workers with no or minor changes in work during the 3-year period, those who lifted weights of at least 25 Kg more than 15 times/week were found to be at higher risk of having low back injury (relative risk (RR) of 1.79). In addition, trunk flexion (RR of 1.72 for flexion $\geq 60^\circ$ for more than 5% of working time/day, based on 8 h shift) and rotation (RR of 1.57 for rotation $\geq 30^\circ$ for more than 10% of working time/day) were also found to be significantly related to back injuries. Davis and Marras [13] studied the contribution of biomechanical, psychosocial, and individual characteristics on spine loading [13]. They found that the biomechanical demands of the task were critical to spinal load (load placement: 4% to 30% of explained variability; load weight: 15% to 55%). Body dimensions (anthropometry) also contributed to the spine load (shear forces: 12% to 58%; compressive forces: 3%). Gender contributed to spinal loads in lesser extent (0.7% to 13.4%). Personality explained between 6% and 19% of the variability, and mental concentration and social environment (psychosocial variables) contributed much less to the spinal loads ($\leq 0.2\%$). Lifting is a risk factor not only for low back injury; in a prospective study done in Sweden involving 3906 pregnant workers, lifting 12 kg or more (50 or more times per week) was found to be a risk factor (odds ratio 1.7) for pre-term birth (less than 37 weeks of gestation) [1].

3.5. Intra-abdominal pressure

Early studies attributed reduction of intervertebral disc pressure during lifting to increased intra-abdominal pressure (IAP) [4]. In 1977, Davis et al. [15] published a paper about the use of radio pills to monitor back stress [14]. After being swallowed by the subjects, these radio pills were able to measure IAP. This pressure is related to the amount of contraction of the abdominal muscles and it was believed that IAP was linearly related to the compression forces acting in the spine. Based on these principles the authors performed several studies about safe levels of manual forces for young males [15–17]. The main recommendation from these studies is that IAP should not exceed 90 mm Hg. This value was derived based on the fact that the incidence rates of back injuries increased significantly when pressures of 100 mm Hg and higher were present in specific occupations. Based on the 90 mm Hg cut-point, the authors suggested several limits for lifting forces. However, this reduction of intervertebral discs pressure by increasing IAP was later refuted. Kumar [69] found that the IAP increase was concurrent with increase in the electromyography activity of back muscles [69]. Later, it was found that a Valsalva maneuver (“voluntary pressurization of the intra-abdominal cavity”) actually increased intervertebral disc pressure in the upright standing posture, even though the maneuver decreased the intervertebral disc pressure by increasing IAP [56]. Additionally, the temporal recording of IAP along with electromyography (EMG) demonstrated that IAP was neither related to force nor EMG [70]. Instead it was found to be a byproduct of other physiological phenomena with no relationship with disc compression. Thus, the effects of increased IAP are controversial and it can not be assumed to always reduce intervertebral disc pressure.

3.6. Spinal compression forces

Chaffin and Park [10] found low back injury incidence rates of 5% and 10% among workers ($n = 411$) when the estimated compressive force at L5/S1 was higher than respectively 2500 N and 4500 N [10]. Another study showed that L5/S1 intervertebral disk compression is a good predictor of back and other overexertion injuries [32]. For jobs with predicted compressive
force at L5/S1 between 4500 N and 6800 N, the authors found a rate of back injuries more than 1.5 times higher than for jobs with predicted compressive force lower than 4500 N (revised results after Waters et al. [89]). Also, cumulative load (compression and shear over an individual’s working life) was shown to be higher in subjects with back pain [71]. Axial compression at L5/S1 intervertebral disk is at a minimum when laying down and at a maximum when sitting with the trunk bent forward. The intermediate compression positions are respectively: standing upright, sitting upright, and standing with the trunk bent forward [53,54].

The National Institute for Occupational Safety and Health (NIOSH) proposed guidelines for the assessment of work physical demands [55]. The guidelines are based on the action limit (AL) and the maximum permissible limit (MPL = 3AL). According to NIOSH, an ideal work environment should keep the exposure under or close to the AL and never exceed the MPL. NIOSH suggests a maximum permissible limit (MPL) for compression at L5/S1 intervertebral disk of 6700 N, and an action limit (AL) value of 3400 N [55]. NIOSH guidelines for compression are based on the studies of Evans and Lisner [23], and Sonoda [23,82]. The results of these studies show that even though the intervertebral discs do not rupture, microfractures of the vertebral cartilage endplates of cadavers of subjects under 40 years old start to happen when applying on average 6700 N of axial load (1500 pounds, approximately 680 Kg). When the spines were from subjects 60 or more years old, the microfractures started to happen when applying average axial loads of 3400 N. Based on these findings, NIOSH suggests a maximum acceptable compression at L5/S1 intervertebral disk of 6700 N for subjects under 40 years old, and 3400 N for subjects with age of 60 or more. In addition to the studies used to define NIOSH guidelines [55], the results of some studies performed after 1981 have supported the initial recommendations. Jager and Luttman [36] compared the results from their proposed biomechanical model for low back axial compression based on the literature regarding lumbar compression strength [36]. The average ultimate axial compression strength (total of 307 lumbar segments) reported by the authors was 4400 N (standard deviation 1900). Norman et al. [58] studied more than 10,000 automotive assembly workers [58]. When the authors compared a sub-group of 104 cases (with low back injury) with 130 controls (without low back injury) the peak shear force on L4/L5 (odds ratio of 2.3) emerged as the strongest factor followed by peak compression force on L4/L5 (odds ratio of 1.9), load in the hands (odds ratio of 1.9), and workers’ perception of work physical demands (odds ratio not reported). The mean peak compression load of the auto-assembly workers who reported low back pain was 3423 N. This value was statistically different (p < 0.001) form the mean value found for the group who did not report low back pain (2733 N). The major limitation of NIOSH 1981 guidelines is that the cut-points are based on cadaver studies with large standard deviations, and the living structures threshold to compression injury for different people might differ (Is it a reliable and valid predictor?). Even NIOSH questions these values, specially the AL value of 3400 N. NIOSH opinion is that this AL value “may not protect the entire workforce” [89]. In addition, the guidelines are based on studies of axial compression only and do not take into account the cumulative effect and temporal characteristics of the exertions over time on the viscoelastic tissues of the body [71,87]. The compression guidelines proposed by NIOSH are widely used, however, as suggested by different studies, they are probably inaccurate and when followed may expose the workforce to demands exceeding its capacity.

Hutton and Adams [34] found a mean value of 10249 N as being representative of the ultimate compressive axial force of intervertebral discs of cadavers of males between 22 and 46 years old [34]. The same authors found that more than 40% of the intervertebral disks prolapsed when 5400 N of axial load was applied to flexed spines (simulated by wedging vertebral bodies) [35]. Additionally, in another study the authors observed trabecular fractures in the intervertebral discs when an average repetitive axial load of 3800 N was applied to simulated hyperflexed spines [2]. Lumbar vertebral fracture due to axial compression has also been studied. In the studies of Brinckmann and colleagues [6–8], repetitive loads from 20 to 75% of the ultimate compressive strength were applied to cadaver spinal segments at a frequency of 15 repetitions per minute, up to 5000 times (maximum time of approximately six hours). The ultimate compressive strength was predicted from the area of the vertebral end plate and from the trabecular bone density measured by quantitative computed tomography. Ninety-two percent of lumbar vertebral specimens suffered fractures when loads of 50 to 60% of the ultimate compressive strength were applied 5000 times over approximately six hours. But, when the percentage of the ultimate compressive strength was increased by only 10%, 91% of the vertebrae suffered fracture after 500 repetitions in approximately half an hour of testing. For loads of 75% of
the ultimate compressive strength, the vertebrae suffered fracture after only 10 repetitions (40 seconds of testing).

3.7. Compound index

In addition to the cut-points mentioned separately for each variable, specifically for the low back, the NIOSH 1991 lifting equation provides a compound measure (lifting index) to assess the risk of lifting-related low back injury [89]. The NIOSH lifting equation and its cut-points are used to assess the risk associated with lifting in many places beside the United States such as Canada and European countries [31]. The lifting index takes several variables into account to calculate the risk of low back injury including object weight, position, hands coupling, vertical and horizontal displacement, posture, L5/S1 compression force, frequency, and duration. The lifting index is a ratio between the actual weight lifted in a task (AWL) and the “recommended weight limit (RWL)” calculated with the equation:

\[
RWL = 23 \times \left[ \frac{25}{h} \right] \times [1 - 0.003(v - 75)]
\times \left[ 0.82 + \frac{4.5}{d} \right] \times f
\times [1 - 0.0032 \times a] \times c
\]

Where: RWL = recommended weight limit in Kg; h = horizontal distance of the hands in relation to the ankles in cm; v = vertical distance of the hands in relation to the floor in cm; d = vertical dislocation of the weight in cm; f = frequency multiplier from a table; a = angular dislocation of the weight; c = coupling multiplier from a table (adapted from Waters [20,89].

The lifting index method (AWL divided by RWL) suggests the following cut-points: when the lifting index is above 1 there is increased risk of low back injury “for some fraction of the workforce”; when the index is above 3, there is elevated risk of low back injury “for many workers”. The main limitations of this index is that it only applies for lifting tasks and does not take into account other tasks that are frequently related to lifting jobs such as pushing, pulling, and carrying. Dempsey [20] studied “primarily lifting/lowering jobs” including 449 workers [20]. Approximately 56% of the workers in this study performed pushing, pulling, and/or carrying tasks in addition to lifting and lowering. Even for lifting tasks there are several restrictions to the use of the method. For example, the lifting equation requires use of both hands, specific ranges of motion, velocity, repetitions per minute, and duration of lifting task, and unrestricted work space. van der Beek et al. [85] analyzed 559 lifting tasks and reported that 57% of the tasks could not be evaluated using the NIOSH lifting equation [85]. In addition, studies have shown that the lifting index (LI) tends to overestimate the risk of back injuries; in a study by Waters et al. [90], only one (LI = 2.7) out of fifteen analyzed lifting tasks presented a LI less than 3 [90]. Another limitation is that many of the individual cut-points used to derive the compound measure are based on psychophysical data (the limitations of this approach were discussed earlier in this paper). Further studies are necessary to test the validity of the cut-points of the lifting index.

4. Discussion

Physical exertion at work is often analyzed using observational methods including nominal classification (light, intermediate, heavy) and/or interval scales (<5 Kg, 5–10 Kg, >10 Kg). For information on the different observation methods, including graphic protocols, questionnaires, and checklists, refer to the reviews conducted by Rohmerta and Mainzer [77], Kilbom [60], Pinzke [74], Coury [11], and Li and Buckle [11,40,60,74,77]. Due to lack of precision of observational methods and the current availability of direct measures, the use of quantitative devices (continuous scale data) instead of observation methods is encouraged [88]. This need is further exemplified by the following quotes: “… direct measurement methods are the only serious option to assess the level of the exerted forces with the accuracy needed for ergonomic epidemiology…” [86]; “… direct observation can be used to capture the postural and temporal demands of work, but quantitative assessment of force is only possible through direct measurement…” [47]. However, caution is needed when using direct measures because the devices may affect the task. Calibration and normalization procedures are also necessary. In addition, suitable instruments need to be developed and/or improved for onsite data collection.

Despite the type of method used to collect the data, the amounts assessed need to be evaluated. Frequently, the success of ergonomic interventions is based on the reduction of the work physical demands. Usually it is accepted that “the less the better”; however, these statements are not good enough. We need to start being more critical in our evaluations in order to succeed in reducing the work-related low back injuries. We
should evaluate the magnitude of present exertion instead of accepting “lower values” after an intervention as a positive outcome. In addition, the epidemiological studies could be designed such that groups of workers exerting specific amounts of back force during the job were compared instead of just comparing exposed and non-exposed workers. This approach would possibly help to determine valid cut-points for back force exertion. So far the studies are designed to study the relationship between higher exposure and higher low back injury incidence instead of testing specific amounts of back force exertion as possible cut-points.

Peak load decreases may not reduce injury risk if cumulative load is increased [18,58,71]. However, no clear cut-points for cumulative back force exertion were found. Further experimental and epidemiological studies in peak load and cumulative exposure are necessary. Often there is job rotation at industrial workplaces, cut-points for shorter exposures than 8h are also necessary. However, usually the workday is still 8h or so, thus the 8h cut-points for each of the jobs in the rotation scheme may further protect the workers against work-related low back injuries by indirectly taking into account the cumulative effect of physical exertions.

There will not be a specific cut-point value that will be applicable to each and every situation because the characteristics of both the working population (i.e. cut-points for pregnant workers [49]; cut-points for older workers [72]) and job task can differ significantly (i.e. cut-points for peak vs. cumulative exertion [18]). However, cut-points are necessary as normative information and should be as specific as possible. Another consideration is in relation to the utility of the available cut-points. Even though, some studies [32] have shown higher incidence of work-related low back injuries in jobs with higher compressive force at L5/S1, this does not mean that the compression is causing the injuries.

Compression may not be the causal factor of a work-related low back injury, but it may be occurring in jobs that also have other factors such as repetition, trunk rotation, and awkward postures that increase the load on back muscles and ligaments. Actually, it is already known that axial compression is not the main cause of intervertebral disc herniation. Even more importantly, less than 20% of low back injuries are discogenic. Notwithstanding, cut-points for L5/S1 compressions are often used as safety guidelines for manual materials handling tasks. More attention should be paid to the erector spine muscle because it is the main trunk extensor [43].

The use of techniques electromyographic recognition of muscle fatigue has potential and interesting applications for work-related low back injury prevention. According to Luttmann et al. [42], “… one of the main interests in the fatigue analysis in occupational health and ergonomics is to define an indicator of the loss in the force generating capacity of the muscle under test…” [42]. Further research is necessary to determine cut-points for back force exertion based on electromyography (EMG) determined muscle fatigue.

Muscle strength is proportional to the cross-sectional area (CSA) of the muscle. EMG fatigue and CSA are used in biomechanical models to predict muscle forces considering the muscles fascicle orientation [43,44]. Jorgensen et al. [38] measured CSA of lumbar spine muscles in different sagital postures using MRI [38]. The mean maximum CSA in the neutral posture was 23.7 cm² (SD = 3.5) for males (n = 12), and 14.8 cm² (SD = 2.0) for females (n = 12). The authors found that the CSA of lower lumbar spine muscles changes with trunk motion, but the maximum CSA of lumbar spine muscles is not affected by trunk posture in the sagittal plane. Gender, body mass, torso area, and spinal curvature can be used to predict lumbar muscles CSA.

Considering that the force generation capability of 1 cm² of muscle is 35 N on average [62], it can be estimated that on average young healthy male and female subjects are able to generate maximal forces with the lumbar spine muscles of approximately 830 N (35 × 23.7) and 520 N (35 × 14.8) respectively. The maximum weight that could be lifted using the back can be calculated using biomechanical models considering the distance of the weight from the body and the trunk posture. However, these are estimates of the maximum strength capabilities and there might be risk on low back injury when 20% of the maximum voluntary contraction is used [39]. The use of data regarding the CSA of the back muscles exerting the forces is needed to define the percentiles of the population that the cut-point is reliable. For this reason, as previously discussed by Jaric et al. [37], normalized instead of absolute strength measures are necessary and require further research.

As commented in Kumar’s Annual Ergonomics Society Lecture in 2003, “… the adjustments made in standards so far do not adequately meet the human limitation” [65]. There are cut-points in the literature for back force exertion, but definitive cut-points were not found. Actually, according to Kroemer [63] “… regarding muscle functions, much research was directed at the isometric condition and, consequently, most information available on muscle strength concerns this static case… data on human body strength… are still largely limited to static or quasi-static conditions” [63].
Most often the available cut-points differ than concur. Further studies are necessary and should quantitatively address the level of both isolated and combined back exposure.

TheNIOSH approach in developing the 1991 lifting equation considering physiological, psychophysical, epidemiological, and biomechanical aspects of exertion [52] meets the most known criteria and present the lowest common denominator for lifting tasks. However, the reference values being used to-date do not seem to be optimally effective. Evidence of this inadequacy is given by the low success achieved so far in controlling work-related low back injuries. In addition, compound indices should also be developed for other types of back force exertion that are common place at work such as pushing, pulling, and carrying. These indices should consider electromyographically determined fatigue, differential viscoelastic properties of tissues, aging, and the cross sectional area of back muscles. We hope that this paper contributes to a more systematic appraisal of back force exertion at work.

Acknowledgements

Funding provided by the Caritas Health Group, the Alberta CIHR Training Program in Bone and Joint Health (Canadian Institutes of Health Research), and by the Education Ministry of the Brazilian Government (CAPES, proc. # 1340-01/8).

References


