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Is there a rational basis for post-surgical lifting restrictions?

2. Possible scientific approach

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Abstract Lifting restrictions post-operatively are quite common but there appears to be little scientific basis for them. Lifting restrictions are inhibitory in terms of return to work and may be a factor in chronicity. The mean changes in functional spinal motion unit (FSU) stiffness with in vitro or computer-simulated discectomies, facetectomies and laminectomies were reviewed from the literature. We modified the NIOSH lifting equation to include another multiplier related to stiffness change post surgery. The new recommended lifts were computed for different lifting conditions seen in industry. The reduction of rotational stiffness ranged from 21% to 41% for a discectomy, 1% to 59% for a facetectomy and 4% to 16% for a partial laminectomy. The recommended lifts based on our modified

equation were adjusted accordingly. There is no rational basis for current lifting restrictions. The risk to the spine is a function of many other variables as well as weight (i.e., distance of weight from body). The adjusted NIOSH guidelines provide a reasonable way to estimate weight restrictions and accommodations such as lifting aids. Such restrictions should be as liberal as possible so as to facilitate, not prevent, return to work. Patients need more advice regarding lifting activities and clinicians should be more knowledgeable about the working conditions and constraints of a given workplace to effectively match the solution to the patient's condition.

Key words Lifting · Surgery · Return to work · Low back pain · NIOSH

Introduction

After surgery it is a common practice to prescribe lifting restrictions. In a companion paper [38] we demonstrated that, in practice, there is no consistency in these restrictions. The restrictions appear to be based on a premise that the spine is weaker and thus subject to re-injury when there has been some disruption of the functional spinal motion unit (FSU) due to surgery. However re-injury is seldom reported in the literature and restrictions do affect return to work [37, 42].

From a biomechanical standpoint, the spine is an unstable structure without proper functioning of the

paraspinal musculature. A lumbar spine, stripped of muscle, will buckle under compressive loads as low as 90 N. Other structures, which could be modified by surgery, are important. The basic shape of the vertebrae, especially the configuration of the facet joints, also add to the stabilization of the FSU. Panjabi's seminal contributions have delineated the specific role of each FSU structure [53–61].

Posture is most important in the risk for low back pain (LBP) and herniated nucleus pulposus (HNP). In one study, positive associations were also seen for frequent lifting with arms extended (relative risk, $RR = 1.87$) and twisting while lifting ($RR = 1.90$). Increased risk of HNP has been associated with lifting while twisting [32]. Lifting with knees straight and back bent increased the risk of

HNP [24]. There is increased disc pressure and intra-abdominal pressure when lifting with knees straight and back bent [4–7, 12–15, 18]. Risk of injury may also be a function of degree of lumbar flexion [62].

Lee et al. [38] determined the lifting capacity of young Chinese males with a smaller body size and lifting capacity than the US population. It was suggested that the vertical discounting factor in the NIOSH lifting guidelines [74] should be modified before the limits can be applied to non-Western populations.

Static and dynamic strength is not the same [72]. Marras and Mirka [45] reported that strength was significantly affected by the trunk angular velocity. Muscle force is needed to accelerate body mass and overcome inertia. Duration of lift is another influencing factor, since strength declines exponentially with duration [72]. Also, the external moment during a dynamic lifting activity is proportional to the speed of the lift [11]. Inertial forces can increase the moment by as much as 60% [40, 41]. If muscles move faster, they cannot generate as much force as when they are exerting a static force or move slowly.

Postures that keep the load far from the spine increase the muscle force and increase the resultant moment on the spine. The force a muscle can produce also varies with the length of the muscle. Muscles that are at their resting length can produce the greatest amount of force. Muscles that are elongated or shortened have a reduced capacity. Also, if the muscles are stretched, one can more easily exceed the strength tolerance of a muscle, causing a muscle sprain. For this reason many lifting guides, including the NIOSH guide, suggest that all lifting occur between knee and shoulder level, where the trunk muscles are close to their resting length. Significantly greater concurrent muscle activation and loading occur during twisting motions of the trunk as a strategy to enhance trunk stability [65]. However, this coactivation increases loading, because the antagonist muscles in the trunk must compete with the agonist muscles. It is noteworthy that asymmetric lifts are associated with a large proportion of LBP cases [45]. Increased shear forces present in asymmetric lifting motions may influence the higher incidence of LBP with this type of exertion. Gallagher and Hamrick [21] and Kumar and Davis [34] found that the external obliques were 31% more active in the asymmetric conditions. In asymmetric tasks, the demands of lifting may be shifted to ancillary muscles with smaller cross-sectional areas [45]. These smaller muscles may be at greater risk of injury during lifting tasks. Thus, based on muscle considerations alone, one would expect differences with gender, anthropometry, age, type of lift (stoop, axial rotation, rate of lift, location of burden) and presence of LBP on lifting capacity.

Adams and Hutton [3] have shown that in forward flexion the disc is less tolerant to compression and the facet joints may disengage, allowing greater torsion on the intervertebral disc, placing the disc fibers in a position much more vulnerable to injury [65, 70].

Materials and methods

Survey of the literature

We surveyed the literature on the measured strength of stiffness loss of the FSU after simulated surgery. Similarly, we reviewed the literature on finite element models (FEM) of the FSU before and after simulated surgery.

Computation of lifting limit

The NIOSH lifting guide includes four lifting components, along with a coupling and asymmetry component [67]. The coupling factor adjusts acceptable load weight for the presence or absence of handles on the load to be lifted. The asymmetry factor reduces the acceptable weight as the lift becomes more asymmetric. The recommended weight limit, defined as a function of these six lifting components, represents a load value that nearly all healthy workers can perform for a substantial period without increased risk of LBP [74]. This guide assumes that a lift is performed in a smooth slow manner. The NIOSH formula (Appendix A) was used in the current study to compute a lifting limit assuming a stiffness loss based on theoretical post-surgical stiffness deficits of 10–90%. Lifting limits were based on several typical lifts of varying amounts of inherent postural difficulty (see Fig. 1). By means of the formulae it is possible to compute the recommended load for a given set of postural constraints. We have made a further modification by changing the recommended load by a factor proportional to the initial change in mechanical properties of the FSU post surgery. This is the thrust of the present study; however, the classical disc pressure studies of Nachemson [48–51] have shown us how different postures and activities can also significantly load the FSU (see Table 1). Various authors have computed the lumbar disc compression and shear during different sagittally symmetric and asymmetric lifting scenarios. Table 2 reviews symmetric lifting data, while Table 3 reviews asymmetric lifting data. There is obviously a wide variation in disc loading values that have been obtained regarding symmetric and asymmetric lifting, due to the differences in tasks performed, load lifted, etc. Hooper and Goel [28] investigated the

Table 1 Compressive Load on the L3 disc during normal activities (from Nachemson [51])

Activity	Load (N)
Supine, awake	250
Supine, semi-Fowler position	100
Supine, traction 500 N	0
Supine, tilt table 50°	400
Supine, arm exercises	500
Upright sitting without support	700
Sitting with lumbar support, back rest inclination 110°	450
Standing at ease	500
Coughing	600
Straining	600
Forward bend 20°	600
Forward bend 40°	1000
Forward bend 20° with 20 kg	1200
Forward flexed 20° and rotated 20° with 10 kg	2100
Sit-up exercises	1200
Bilateral leg lift	800
Lifting 10 kg, back straight, knees bent	1700
Lifting 10 kg, back bent	1900
Holding 5 kg, arms extended	1900

Table 2 Review of sagittally symmetric lifting tasks (*S* static, *D* dynamic, *N/R* not reported, *BW* body weight) (from Hooper [29])

Author	Type of lift	Load (N)	Model	Flexion moment (Nm)	Disc comp. (N)	Disc Level
Eckholm [17]	Leg, back	126	S	160 217	3461 4390	L5-S1
Leskinen et al. [40]	Leg, back	147	D	N/R	5866 6365	L5-S1
Freivalds et al. [20]	Leg	Max.	D	N/R	6000 to 7000	L5-S1
Leskinen et al. [41]	Leg	147	S	N/R D	4033 5866	L5-S1
	Back		S D		4033 5866	
McGill and Norman [46]	Arms out	177	S D	232 276	5218 6931	L4-L5
Bush-Joseph et al. [11]	Leg, back, free	150	D	N/R	18% BW 17% BW 17% BW	L5-S1
Han [27]	Leg, back	0–180	D	112 161	765 601	L3-L4

Table 3 Review of asymmetric lifting tasks (from Hooper [29]) (*F* flexion, *LB* lateral bending, *AT* axial twist)

Author	Task (lift)	Weight (N)	External moments (Nm)	Internal disc lateral shear	Internal disc comp.	Internal disc A/P shear	Level
Kromodihardji and Mital [33]	Symmetrical Asymmetrical	292 262	–90 to 360 F –210 to 240 LB –60 to 0 AT	Shear forces lumped	4706 3751	395 529	L5-S1
Jager and Luttman [30]	Asymmetrical	392	325 F 50 LB 100 AT	200	6000	900	L5-S
Hooper [29]	Symmetrical Asymmetrical	90	181 F 86 LB 29 AT	74 139	4122 4406	1142 1134	L3-L4 L4-L5

Table 4 Mean maximum disc forces at L3-L4 and L4-L5 while lifting 90 N (from Hooper [29])

Disc	Mean loading (N)	Mean loading (N)	Mean loading (N)
L3-L4	0°	45°	90°
Lat. shear	35.4	55.5	66.8
Comp.	3764.7	3899.2	3990.4
A/P shear	944.4	1017.8	1031.5
Flex	19.8	21.3	22.0
Twist	0.2	0.5	0.7
LB	1.7	4.5	6.3
L4-L5	0°	45°	90°
Lat shear	43.9	91.9	146.7
Comp.	3483.4	4142.3	4290.3
A/P shear	662.2	1000.0	1058.5
Flex	21.5	23.1	23.9
Twist	0.2	0.5	0.7
LB	0.9	2.4	3.4

consequences of asymmetric lifting on external and internal loads at the L3-L5 lumbar levels. They found the maximum disc forces at L3-L4 and L4-L5 during three different types of asymmetric, 90-N lifts: lifting straight up (0° rotation) and setting the load down, lifting and rotating 45° before setting the load down, and lifting and rotating 90° before setting the load down (Table 4).

Results

Survey of the literature

The spine is naturally shaped to properly distribute and transfer the loads. Therefore, any surgical technique involving dissection of spinal components (i.e., removal of some or all of the laminae, facets, or discs) can disrupt the natural equilibrium of the spinal elements. For each procedure, Panjabi observed an increase in the range of motion (ROM) of the FSU, which can lead to more pain. This is supported by his studies using an external fixator to stabilize the spine [63].

Farfan [19] found that the facet joints contribute 50% of the torsional resistance and Lorenz et al. [43] found that up to 25% of the axial load bearing is borne by the facets, and this is diminished by the removal of one facet. The facets and discs together give 80% of the torsional resistance (roughly shared between the disc and facets). A total facetectomy produced an increased motion of 63% in flexion, 78% in extension, 15% in lateral bending, and 126% in axial rotation [2], and a partial facetectomy increased FSU motion in flexion, lateral bending, and clockwise axial rotation [35, 42]. Lehmann et al. [39] reported that removal of both facet joints significantly destabilized the lumbar spine, and a partial destabilization was seen with the removal of one facet joint.

Nachemson [51] found that more degenerated discs were less flexible in flexion and extension. However, Mimura et al. [47] found that in flexion-extension, the ROM decreased and the neutral zone/ROM (NZR) increased with degeneration. In axial rotation, both the neutral zone (NZ) and the NZR increased with degeneration [47]. In lateral bending, the ROM significantly decreased and the NZR increased with degeneration. In all three loading directions, the NZR increased, indicating greater joint laxity with degeneration. In axial rotation, a tendency for the NZ, in particular, to increase with disc degeneration was observed [56].

Surgery to the intervertebral disc increased the coupled lateral rotation under the application of axial torque [52]. Thus, the disc was the structure that most resisted the coupled lateral rotation. Injury to the articular facets changed the coupled flexion rotation under axial torque to extension rotation. Therefore, the facets were the structures that forced the vertebra into flexion rotation.

Panjabi et al. studied intact and surgical specimens in response to dynamic and quasistatic loads. The sequential injuries were: cutting a square window in the annulus on the right, posterolateral to lateral to the neural foramen, and total nucleotomy. A significant increase in major as well as coupled motions with disc injuries was observed for almost all loading modes. Symmetric motion about the midsagittal plane was absent after the injury. The authors hypothesized that it would lead to an asymmetric movement of the apophyseal joints [59]. Goel et al. found that the most significant increase in motion, for specimens with partial discectomy, occurs in flexion followed by axial rotation and lateral bending. They also found increases in motion at the injured level (L4-L5) after total discectomy were significantly greater than the increases after partial disc removal [22]. Seroussi et al. showed that nucleus removal leads to altered load bearing in the disc [66]. Goel et al. reported a significant increase in the ROM for all loading modes except extension when a total discectomy was performed. A significant but smaller increase in ROM for subtotal disc removal was also observed. Both partial and total discectomies produced a significant amount of translational motion in response to

left lateral bending. They attributed the one-sided instability to the combination of injuries to the annulus and the right capsular ligament. Goel et al. have also shown more significant changes to the motion with removal of the nucleus pulposus as opposed to the annulus [22]. Tibrewal et al. found that discectomy by fenestration and minimal resection of the lamina did not produce instability [73].

Goel and Kim, using the FEM, reported that a total denucleation with other structures left intact, and bilateral total discectomy injuries induced in the intact model, led to a two-fold increase in flexion-rotation. Total removal of the nucleus increased the contact stress across the facets. The force on the facets increased by 80% following denucleation [23]. Similar results have been reported by Dunlop et al. [16]. Absence of the facets in the models of Kurowski and Kubo, and Shirazi-Adl et al. resulted in loads being transferred to the disc [36, 68].

FEM studies of Goel et al. found that the instrumented models were stiffer than the intact model. However, unilateral fixation with bilateral fusion was found to result in coupled motions as compared with the case in which two plates were used to stabilize the same injury. This may lead to changes in the structures before the fusion mass takes over after its healing [24, 25]. However, the rigidity provided by the unilateral fixation with bilateral fusion seems adequate to obtain solid fusion and early mobilization of patients, because clinical follow-ups of patients undergoing this procedure have revealed solid fusion and no apparent complications [31].

To demonstrate the increased flexibility or decreased stiffness of the lumbar segment or region due to surgery, we used moment and rotation data from three studies in the literature [1, 22, 67]. In each study, intact segments were modified or "injured" surgically, resulting in an increased major or main rotation. Within each study the same magnitude of moment was applied to the specimen in the intact and injured conditions, the results being reported in terms of rotations. Results were also reported in terms of flexibility – the ratio of the resultant rotation divided by the applied moment – or in terms of stiffness – the ratio of the applied moment divided by the resultant rotation. We must caution the reader that this expression of the flexibility or stiffness of the lumbar segment or region is a simplification for the purpose of illustration. Complete description of the flexibility or stiffness of an FSU or region requires consideration of its six degree-of-freedom load/torque-motion, coupling, viscoelastic, and load/moment application method characteristics [8, 48, 64, 68]. Continuing the illustration, if we find the simple "stiffness" (applied moment/resultant rotation) of the segments tested in the studies by Abumi et al., Goel et al., and Sharma et al. [1, 22, 67], we can normalize the stiffness of the surgically modified or injury conditions by the stiffness of the intact condition (Table 5), thus providing a sense of the reduction in stiffness of the segment or region due to surgery. For example, in Abumi et al.'s [1] work, a

Table 5 A–C Normalized rotational stiffness: injured/intact

A Values from Abumin et al. [1] (*A* intact, *B* cutting of supraspinous and interspinous ligaments, *C* left unilateral medial facetectomy, *D* bilateral medial facetectomies, *E* left unilateral total facetectomy, *F* bilateral total facetectomy)

	A	B	C	D	E	F
Flexion	1	0.81	0.73	0.69	0.66	0.61
Extension	1	1.07	0.95	0.87	0.75	0.56
L ax rot	1	0.93	0.99	0.91	0.89	0.41
R ax rot	1	0.95	0.97	0.90	0.67	0.48
R lat bend	1	1.03	0.93	0.90	0.89	0.87
L lat bend	1	0.90	0.91	0.87	0.85	0.79
Average of above	1	0.95	0.91	0.86	0.78	0.62

B Values from Goel et al. [25] (*A* intact, *B* partial laminectomy, *C* partial facetectomy, *D* subtotal discectomy, *E* total discectomy)

	A	B	C	D	E
Flexion	1	0.84	0.86	0.71	0.59
R ax rot	1	0.91	0.77	0.77	0.71
R lat bend	1	0.96	0.90	0.79	0.74
Average of above	1	0.90	0.84	0.76	0.68

B Values from Sharma et al. [67] (*A* intact, *B* no ligaments, *C* no ligaments and no facets)

	A	B	C
Flexion	1	0.60	0.60
Extension	1	0.98	0.52
Average of above	1	0.79	0.56

bilateral total facetectomy would result in an average normalized rotational stiffness of 0.62, or a reduction in stiffness of 38% from the intact condition.

Computation of lifting limit

Currently, the best estimate we can make of the recommended weight to lift (RWL) for the post-surgical patient is based on the stiffness of the FSU. Although a simplification, it is a start that combines knowledge of the biomechanics of the FSU with the experience that developed the NIOSH guidelines. With a normal, healthy spine, an individual could be exposed to lifting environments as defined in the guidelines. Any procedure that decreased the segment stiffness by a particular percentage would result in a proportional reduction in the patient's lifting capacity (Fig. 1). Assuming a lifting restriction is based on the decrease in stiffness of the motion segment, RWLs can be determined for simple and complex lifting conditions via the NIOSH 1991 Lifting Guidelines [74] and Hyperlift (Chase Ergonomics, Albuquerque, 1994). The lines in the chart in Fig. 1 are examples that can be used for various lifting conditions. To determine the maximum lift load using this graph, determine the percentage lifting restriction

Fig. 1 Computation of lifting limit. The *A* line represents pro-ratio of a weight of 23.2 kg based on lifting restrictions: starting from a vertical location of 1 m above the floor, moving vertically, upward 0.25 m, without any twisting. The *B* line represents pro-ratio of a weight of 21.0 kg based on lifting restrictions: starting from a vertical location of 1.0 m above the floor, moving vertically, upward 0.25 m, while axially twisting 30° to the right or left. The *C* line represents pro-ratio of a weight of 15.6 kg based on lifting restrictions: starting from a vertical location on the floor, moving vertically, upward 1.0 m, without any twisting. The *D* line represents pro-ratio of a weight of 14.1 kg based on lifting restrictions: starting from a vertical location at the floor, moving vertically, up 1.0 m, while axially twisting 30° to the right or left

on the *x*-axis, draw a line vertically upward to where it intersects one of the four lifting condition or *A*–*D* lines, then determine the load magnitude at that point from the *y*-axis [i.e., the NIOSH 1991 RWL (kg) axis]. Figure 1 gives a series of four examples of the lifting limits recommended by the NIOSH Lifting Guidelines [74], pro-rated over levels of lifting restrictions ranging from 0 to 100%. For example, a normal, healthy individual, with no (or 0%) lifting restrictions could lift loads according to the NIOSH guidelines and would determine their levels at the left hand side of the graph, over the 0% value on the *x*-axis. Under the best lifting conditions (line *A*, Fig. 1) the healthy individual should lift only 23.2 kg. However, a patient who had undergone a bilateral total facetectomy – a procedure known from laboratory research [1] to decrease flexion stiffness by an average of 39% (to a normalized stiffness level of 0.61) – would find recommended maximum lifting levels at the 39% lifting restriction level. Under the best lifting conditions (line *A*, Fig. 1), that patient could lift 14.2 kg. Under lifting conditions (line *D*, Fig. 1) that included lifting an object from the floor up 1.0 m and twisting 30° to the right or left, the recommended weight to be lifted would be 8.6 kg. The lines on the chart (Fig. 1) represent only four of many more possible conditions as determined by the NIOSH 1991 Lifting Guidelines. All lifting conditions can be calculated without the use of the graph in Fig. 1. Multiply the RWL (calculated from the NIOSH 1991 Lifting Guidelines) by the appropriate normalized stiffness value for the condition, found in Table 5 (a new multiplier: *SM*, see the

Appendix). For example, in case A: $23.2 \text{ kg} \times 0.61 = 14.2 \text{ kg}$, and in case D: $14.1 \text{ kg} \times 0.61 = 8.6 \text{ kg}$.

Discussion

In advocating early return to work some biomechanical principles should be imparted to the patients. From a mechanical standpoint, the muscles are placed relatively close to the spine. Therefore, they act with small moment arms and have to produce large forces, which in turn create large compression and shear forces on the lumbar spine. Reducing the load moment (i.e., holding loads close to the body) will reduce spine load. Thus, the posture of the individual is important. Large internal forces and moments are created simply by the act of maintaining, for example, a forward bending posture. In addition, forces and moments are created by the weight of the object to be handled and by the location of the object relative to the spine. Given the same object weight, these latter forces and moments are largely determined by the origin and end points of the materials-handling maneuver. In symmetric lifting activities, the horizontal and vertical locations of a load at the start of a lift and its end point also determine the travel distance and, therefore, to some degree, the duration of the lifting activity.

Symmetric lifting, i.e., holding the load with both hands in front of the body, is the preferred method of manual materials handling [10]. In that situation, the muscles can be used most efficiently and the stresses are bilaterally equalized. However, asymmetric lifting is also common in industry. Finite element models of the disc have indicated that the disc is weakest with asymmetric loadings [9, 68–70]. Thus, postoperative patients should be advised to avoid lifting in an asymmetric fashion.

On the basis of the previous findings, a simple set of guidelines for lifting can be created. These guidelines include:

1. Maintaining a symmetric upright posture, thereby avoiding forward flexion, lateral bending, and twisting
2. Lifting the object as close to the body as possible
3. Keeping the weight of the object as low as possible
4. Whenever possible, lifting symmetrically, using both hands, and

5. Lifting smoothly without major jerks and at a moderate lifting speed.

There is a basis for the concern that the FSU may be weakened post surgery. However, probably because of variations in both the technique and between specimens there is not a great consensus on what the mechanical deficit is for a given operation. It must be clear, however, from the previous discussion that there is no scientific basis for current lifting restrictions. In a companion paper it was found that the restrictions are not consistent for the same surgery and are not even consistent between surgeons for the same patients. Not specifying other parameters that determine the load on the spine, such as posture and asymmetry, nor taking age, gender, physique, or anthropometry into account is obviously scientifically incorrect. Merely specifying the weight without the other parameters of lifting has no scientific basis. The use of the modified NIOSH equations may be helpful, but needs to be tested in clinical practice.

We must be very careful in our recommendations. While advice to “do as little as possible” may be expeditious, thought to be helpful, and legally benign, it may sentence the patient to loss of livelihood, loss of housing, and loss of family. This present work has presented a rational way to estimate loads that post-surgical patients are able to handle, enabling a graduated and early return to work, thus allowing patients to get on with their lives.

The present authors favor early return to work with limited restrictions as to load and for a limited time period. The limits could be based on our new recommendations, which are based on the actual lifting task and on mechanical alterations post surgery. Patients should be fully informed about risk factors in lifting to avoid (twisting, bending, etc.). Patients should very quickly be empowered to lift tolerance (i.e., up to the limit appropriate for them). Clinicians must take a more proactive role in finding out what the real working conditions are and offering pragmatic suggestions to ensure early return to work. As noted in a companion paper [44], biomechanical considerations support the use of early physical therapy to provide musculature support for the compromised motion segment post surgery.

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Appendix

The basic National Institute of Occupational Safety and Health (NIOSH) lifting equation [74] is as follows:

Recommended Weight Limit

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$$

Component	Metric	US customary
LC = load constant	23 kg	51 lbs
HM = horizontal multiplier	25/H	10/H
VM = vertical multiplier	$1 - [0.003 \text{ abs}(V - 75)]$	$1 - [0.0075 \text{ abs}(V - 30)]$
DM = distance multiplier	$0.82 + (4.5/D)$	$0.82 + (1.8/D)$
AM = asymmetric multiplier	$1 - (0.0032A)$	$1 - (0.0032A)$
FM = frequency multiplier (from Appendix Table A.1)		
CM = coupling multiplier (from Appendix Table A.2)		

where

H = horizontal distance of hands from midpoint between the ankles. Measure at the origin and the destination of the lift (cm or in.)

V = vertical distance of the hands from the floor, at the origin and destination of the lift (cm or in.)

D = vertical travel distance between the origin and the destination of the lift (cm or in.)

A = angle of asymmetry i.e. angle displacement of the load from the sagittal plane. Measure at the origin and destination of the lift (degrees)

F = average frequency of lifting, measured in lifts/min. Duration is defined as: ≤ 1 h; ≤ 2 h; or ≤ 8 h, assuming appropriate recovery allowances (see Appendix Table A.1)

A = absolute value

We have modified the above equation so that now:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \times SM$$

where: SM = normalized stiffness due to a specific surgery

Appendix Table A.1 Frequency multiplier (FM), with values of V given in centimeters (75 cm = 30 in.)

Frequency (lifts/ min)	Work duration					
	≤ 1 h		≤ 2 h		≤ 8 h	
	V < 75	V $\geq$ 75	V < 75	V $\geq$ 75	V < 75	V $\geq$ 75
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
> 15	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table A.2 Coupling multiplier (whether the load has handles or good coupling versus a smooth box with no handles or poor coupling)

Couplings	Coupling multipliers	
	V < 75 cm (30 in.)	V $\geq$ 75 cm (30 in.)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90