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Biomechanical risk assessment during field loading of hydraulic stretchers into ambulances

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ABSTRACT

The process of loading a stretcher into an ambulance is known to cause a high incidence of back injuries among paramedics. This study aimed to assess the forces at L5/S1 during real-life stretcher loading activities and to determine the variables that contribute significantly to these forces. Analyses involved 58 paramedics (111 shifts) and 175 stretcher loading activities. Estimates of compression and shear forces at L5/S1 were calculated using the 3DSSPP program. Seventy-one percent of loading activities exceeded the safe loading level of 3.4 kN compression force at L5/S1 (mean: 3.9 kN, min−max: 2.1−7.0 kN). About 92% of the variance can be predicted from a combination of several variables, notably hand load (mean: 0.72 kN/number of paramedics) and back sagittal flexion (mean: 32°). Recommendations to reduce the risk of back injuries are proposed with regard to stretcher and ambulance loading design as well as training in stretcher lifting for paramedics.

Relevance to the industry: The results of this study suggest that ambulance stretcher manufacturers should make ergonomic design changes to reduce the physical strain on paramedics' backs during the process of loading a stretcher into an ambulance. Other preventive measures (e.g., training) must be formulated and applied to reduce the risk of back musculoskeletal disorders during the loading of stretcher patients. For instance, training should focus on back posture, teamwork and equipment/patient positioning on stretchers.

1. Introduction

The evaluation and stabilization of patients' condition and their transportation constitute the core business of ambulance services (Chaffin et al., 2006; Dicaire et al., 2000). Some patients are able to move independently but most need transportation on a stretcher, which must be loaded into an ambulance by paramedics at the call site and unloaded at the hospital. The loading process is known to cause a high rate of back injuries (Cooper and Ghassemieh, 2007; Furber et al., 1997; Prairie, 2010; Prairie and Corbeil, 2014; Studnek et al., 2012) and other adverse events (Chaffin et al., 2006; Wang et al., 2009). Very few studies have focused on the cause of these injuries.

Research into manual handing suggests that the most probable failure mode for low back injury results from compression of the L4/L5 or L5/S1 intervertebral disc (Gauthier, 2006; Waters et al., 1994). Cooper and Ghassemieh (2007) showed that, during simulated loading/unloading activities with a patient load of 75 kg, in all stretcher systems tested (ramp, Easi-loader, tail-lift), some forces exceeded the force limits. Using the failure mode of 3.4 kN of compression force to assess the risk of injury (Waters et al., 1993), they demonstrated that most loading systems met this load criterion on the L4/L5 intervertebral disc (Cooper and Ghassemieh, 2007). These authors also extrapolated their results for a 150-kg patient (up to 150 kg must be carried on stretchers) and found that the greatest compression for the Easi-loader system (8.2 kN) was recorded when paramedics initially lifted the stretcher. It is therefore possible that real-life loading activities may involve loads

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that exceed the safe loading levels; consequently, the authors recommended that this system should not be used in the future. Spine loading is generally estimated at either the L4/L5 or L5/S1 level. L5/S1 usually has the largest moment arm on the back (Chaffin et al., 2006; Hart and Staveland, 1988) and, according to Rajaee et al. (2015), lifting tools that provide estimates of spine loads (including 3DSSPP) predict greater shear at the L5/S1 level and generally greater compression force at this level as well. For this reason, the L5/S1 level was chosen in this study to represent lumbar stresses during lifting activities.

In a recent field study, Prairie and Corbeil (2014) demonstrated that real-life situations involving loading/unloading hydraulic stretchers into ambulances are associated with very large individual variations in back posture. This variability may be explained by the variable and unpredictable work contexts that paramedics must deal with: different environmental factors (lighting, climate, physical work environment), social interactions, organizational factors (level of emergency, team members) and individual factors (anthropometry). Posture and anthropometric factors have a significant impact on the assessment of back compression and the risk of injury (Chaffin et al., 1999; Service Canada, 2013).

Some recent stretcher systems contain hydraulic lifting mechanisms designed to reduce loading and unloading times. These mechanisms tend to increase the total mass of the stretcher and therefore the forces required for paramedics to load and unload stretchers and patients (Doormaal et al., 1995; Prairie, 2010; Prairie and Corbeil, 2014; Wang et al., 2009). To our knowledge, a biomechanical risk assessment of these hydraulic stretchers has not yet been done.

The aims of this field study were to: (1) assess compression and shear forces at L5/S1 and the risk of injury while loading a hydraulic stretcher into ambulance on the job; (2) determine the main variables that have a significant effect on compression and shear forces during real-life stretcher loading activities. It is anticipated that the results of this research will provide widely applicable guidelines for ambulance companies.

2. Material and methods

2.1. Participants

A total of 58 paramedics were volunteer participants and were observed during consistent 8- or 12-h day ($n = 34$) and night ($n = 24$) work shifts. The male to female ratio of the participants (78% men and 22% women) was similar to the ratio in the paramedic population. Half of all participants had a body mass index higher than 25 kg/m^2. Participants were recruited via an electronic mailing list. The participants' demographic characteristics are presented in Table 1. None had been on sick leave within one month of the time of the study. Participants signed an informed written consent form prior to participating in the study. Ethics approval for this study was obtained from the institutional review board, in accordance with the Helsinki Declaration.

Table 1
Paramedics' demographic characteristics ($n = 58$).

	Mean	SD	Median	Min	Max
Age (years)	36.8	11.3	35	21	61
Experience (years)	12.5	11.1	9	1	35
Weight (kg)	77.6	14.1	77.2	52.2	111.4
Height (m)	1.75	0.09	1.75	1.52	1.93

SD = standard deviation; Min = Minimum; Max = Maximum.

2.2. Data collection

This research was carried out at two Quebec ambulance companies, Coopérative des techniciens ambulanciers du Québec and Dessercom. Data were collected on 111 days over 15 months from June 2011 to August 2012. During a shift, the paramedics worked in pairs and shared the responsibility for driving and attending to patients. Data were collected on one member of each team, who might perform both roles during the shift. The videos made by the observer were recorded during the activities from the paramedics' arrival on the scene to the delivery of the patient to the hospital when the observer received verbal consent for participation from the patient, the family, the other paramedic and the other persons involved (e.g., police officer, firefighter, nurse, doctor). This study focuses on loading stretchers and patients into the ambulance. This task was described as the activities executed from the point when paramedics were 1 m away from the ambulance with a patient on the stretcher until the stretcher's security system was engaged in the ambulance.

2.3. Equipment

The observers used a digital video camera (GZ-HD30u or GZ-HD500, JVC, Mississauga, ON, Canada) to record all activities. A strain gauge force dynamometer (DFE2-200, Chatillon, FL, USA) was used to measure the weight of the equipment used by the paramedics, as well as to measure hand force during simulated stretcher loading activities in order to determine different moment arms.

2.4. Data analysis

2.4.1. Paramedics' hand load

To estimate the paramedic's hand force, static moments about the stretcher's head-end wheel contact point (Fig. 2) were determined based on the weight of the patient (F_{Px}), the weight of the stretcher (F_S), the weight of the equipment installed on the stretcher (F_E), the lifting force (F_{Lift}), and the number of paramedics involved in lifting (P). Four equipment positions were observed during field capture, as illustrated in Figs. 1 and 2. Equations (1) and (2) were used to assess the hand load (F_{Hand}), as described below:

$$F_{Lift} = \left(F_{Px} \times \mathrm{D_{Px}} + F_S \times \mathrm{D_s} + \left(\sum_{i=1}^{n} F_{Ei} \times \mathrm{D_{Ei}} \right) \right) \Big/ D_{Lift} \quad (1)$$

$$F_{Hand} = F_{Lift} \Big/ P \quad (2)$$

F_{Lift} represents the total force required to support the stretcher at the beginning of the lift and D_{Lift} is the moment arm between the paramedic's hand and the stretcher's head-end wheels. The moment arm of D_{Lift} was 1.977 m, measured with a tape measure, and was considered constant for all the paramedics. The moment arm for the stretcher was examined during simulated stretcher loading activities (stretcher alone) using a gauge force dynamometer and Equation (1) ($D_{Px} = 0.964$ m). Other simulations were performed to measure hand force during loading of the stretcher loaded with a patient, as well as during loading of the stretcher with equipment positioned at different locations. Moment arms for the patient and equipment ($D_{Px} = 0.964$ m; for D_E, see Table 3) were obtained using those hand force values and Equation (1). Several assumptions were made in evaluating forces: paramedic forces applied on the stretcher were assumed to be evenly distributed between the two paramedics during a team lift and evenly

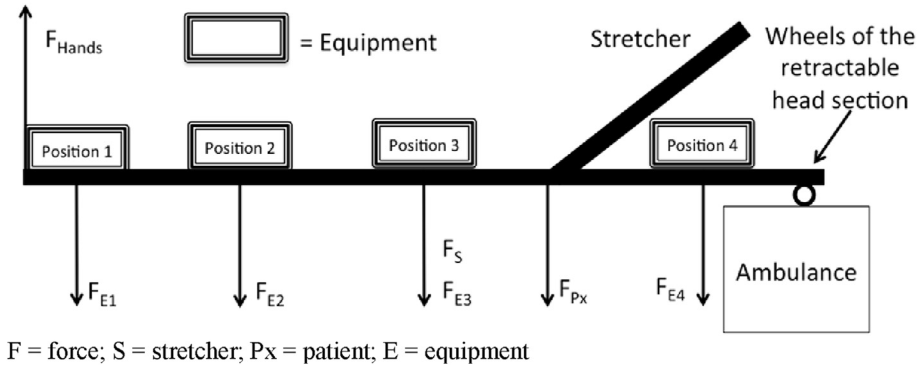

Fig. 1. Forces applied while loading a stretcher into an ambulance.

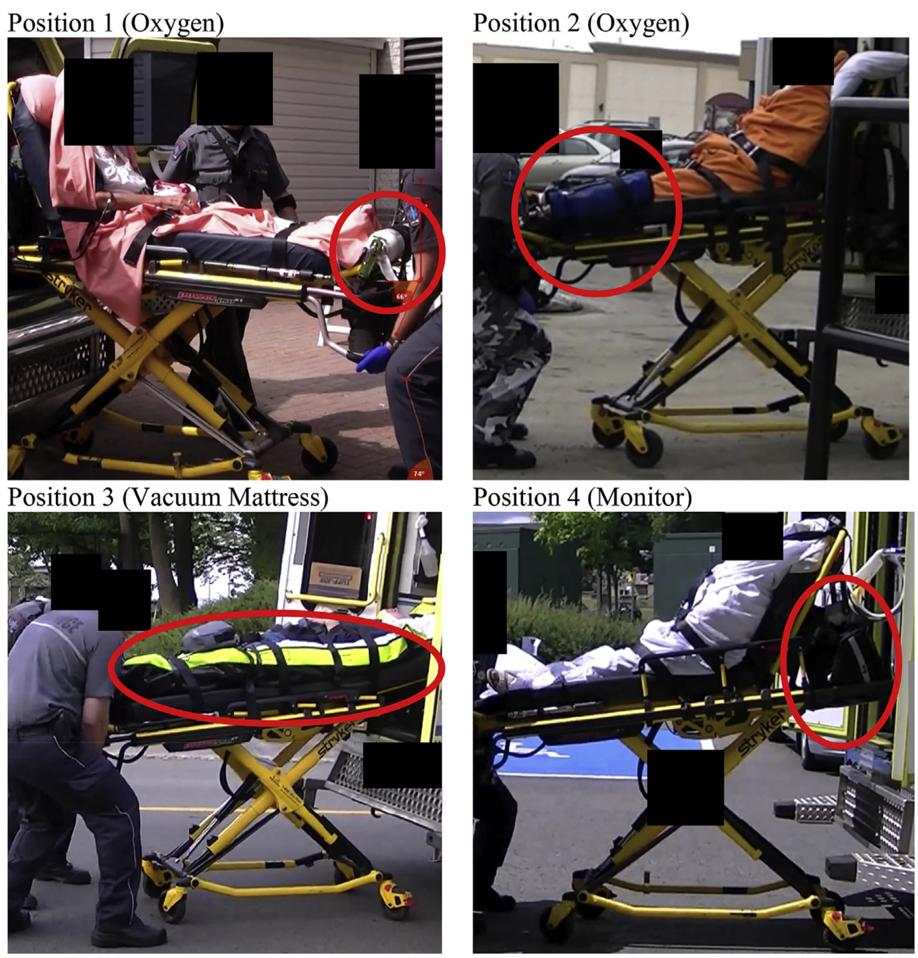

Fig. 2. Equipment positions on the stretcher.

Table 2
Summary of data collected.

Variables	Value
Mean work shift duration (hours)	10.0
Number of days of observation	111
Number of hours of observation	1122
Number of emergency calls made	388
Number of emergency calls recorded	311
Number of stretcher loading operations recorded	258
Number of stretcher loading operations analyzed	175

distributed between each paramedic's two hands; hand force is assumed to be oriented vertically.

2.4.2. Back compression and shear force for L5/S1 intervertebral disc

Compression and shear force were evaluated using the sagittal plane low back analysis of the Three Dimensional Static Strength Prediction Program (3DSSPP, University of Michigan, Ann Arbor, MI, USA). A technical discussion of the static strength model used is provided in the literature (Borg, 2005; Chaffin et al., 2006).

Images were extracted from video recordings in order to obtain a full picture of the paramedics' posture in the sagittal plane. Postural analysis, using the Kinovea 8.15 open source program, was performed at the beginning of the stretcher lifting, that is, when the wheels closest to the paramedics were about to leave the ground

Table 3
Weight of equipment and different moment arms (D_E) depending on its position in relation to the contact point of the stretcher's head-end wheels.

Equipment	Weight (kg)	Position 1		Position 2		Position 3		Position 4	
		D_{E1} (m)	N	D_{E2} (m)	N	D_{E3} (m)	N	D_{E4} (m)	N
First aid bags	8.1	–	–	–	–	–	–	0.175	1
Monitor	10.7	–	–	1.569	2	–	–	0.133	73
Oxygen	4.4	1.682	14	1.474	19	–	–	0.186	5
Vacuum mattress	6.4	–	–	–	–	0.989	17	–	–
Monitor + first aid bags	18.8	–	–	–	–	–	–	0.237	9
Monitor + oxygen	15.1	–	–	–	–	–	–	0.313	9

– = Position or combination not observed during field observation; N = number of times observed out of 175 loading activities.

(Fig. 3). The sagittal segmental angles of the forearm, upper arm, back, upper leg and lower leg were used as input for the 3DSSPP model. Other input parameters included paramedics' height, weight and gender, as well as hand load.

Back compression and shear forces for the L5/S1 intervertebral disc were computed by the 3DSSPP software. These values were then compared to the compression force criterion limit of 3.4 kN (Doormaal et al., 1995; Prairie, 2010; Waters et al., 1994) and shear force criterion limit of 1 kN (Gallagher and Marras, 2012) to assess task safety.

2.5. Statistical analysis

Descriptive statistics were reported for all dependent variables. In addition, multiple regression analyses were performed to determine the sets of predictors influencing compression and shear forces at L5/S1, using a forward stepwise model (F to enter = 3.84, F to remove = 2.71). The predictor variables included those associated with (1) gender (man or woman), weight (kg), and height (cm); (2) the segmental angle (°) of the knees, hips, back, elbows and shoulders at the beginning of the lift; and (3) hand load (N). All analyses were performed with Statistica software 8.0 (Statsoft, Tulsa, OK, USA). The significance level adopted in this study was $p < 0.05$.

3. Results

3.1. Overview of the results

A total of 258 stretcher loading operations were executed over the 311 emergency calls recorded (83%; Table 2). A total of 83 loading operations were removed from analysis because of inadequate video quality or unauthorized video recording. One hundred and seventy-five real-life loading stretcher activities were analyzed in this study.

The duration of the stretcher loading activity was 24.7 ± 8.6 s (ranging from 11.0 to 63.0 s). Mean hand load force was 703 ± 101 N (454 N minimum and 1138 N maximum).

Hydraulic stretchers (Power-PRO™, weight = 56.7 kg, Stryker, Kalamazoo, MI, USA) constitute the loading system used in Quebec City (Canada) and the most commonly used through the province. The hydraulic lifting mechanism is designed to raise and lower the patient with the touch of a button.

The stretcher's influence on the lifting forces represented on average 49.1% of the lifting force (30% minimum and 76% maximum). The patients' weight represented between 24% and 70% of the lifting force. Other equipment (e.g., first aid bags, ZOLL E Series monitor defibrillator, oxygen tanks and vacuum mattress) was sometimes carried during loading activities. In general, equipment was installed in position 4 in 65% of the work tasks studied (Fig. 2 and Table 3). The equipment and its location represented between 0% and 14% of the lifting force.

Paramedics loaded the stretcher into the ambulance in teams of two in 87% of cases and alone the rest of the time. When a paramedic loaded the stretcher alone, the hand load for one paramedic was 1.8 times greater than when it was done by a team (359 ± 52 N compared to 654 ± 68 N alone). The typical posture adopted by a paramedic when starting to lift a stretcher is presented in Table 4 and Fig. 4. No linear relationship was found between back, arm and leg segmental angle and paramedics' height ($p > 0.49$; $r < 0.05$). Small but significant linear relationships were found between forearm and thigh segmental angles and paramedics' height ($p < 0.05$; $r = 0.16$; and $p < 0.05$; $r = -0.15$, respectively).

Fig. 3. Posture adopted by paramedics at the onset of stretcher lifting.

3.2. Compression and shear forces

The average compression and shear forces applied on a paramedic's back at L5/S1 were 3884 ± 838 N (2054 N minimum and 6971 N maximum) and 549 ± 101 N (348 N minimum and 898 N maximum) respectively. In the 175 stretcher loading activities analyzed, 71% exceeded the compression criterion limit and none

Table 4
Mean, standard deviation, minimum and maximum segmental angles of the posture adopted by paramedics at the onset of stretcher lifting.

Angles	Mean	SD	Median	Min	Max
Back (°)	32.0	10.4	32	11	61
Arm (°)	−4.8	8.0	−5	−34	10
Forearm (°)	63.1	15.3	65	20	89
Thigh (°)	37.9	10.9	39	2	68
Leg (°)	70.5	11.1	70	55	105

° = Degree; SD = Standard deviation; Min = Minimum; Max = Maximum.

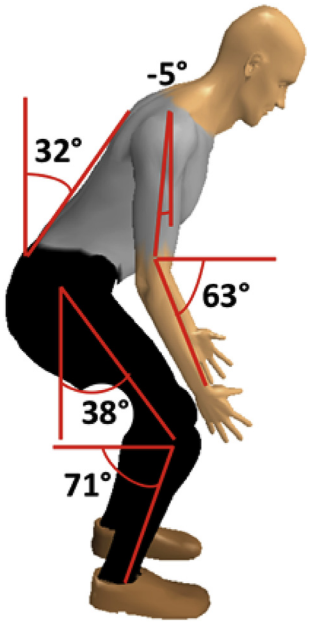

Fig. 4. Mean segmental angles of the posture adopted by paramedics at the onset of stretcher lifting.

exceeded the shear criterion limit (Fig. 5). All stretcher loading activities performed alone exceeded the compression criterion limit.

3.3. Predictors of compression forces

Multiple regression analysis was performed with all the independent variables. The combination of nine variables predicted 92% of the variance in compression forces at L5/S1 during stretcher loading and the standard error of the estimate was 243 N. The three main variables of the models are hand load, back sagittal flexion and elbow angle (Table 5).

3.4. Predictors of shear force

Another multiple regression analysis was performed and eight variables remained in the final model, explaining 98% of the variance in shear forces at L5/S1 during loading stretcher. The standard error of the estimate was 15 N. The three main variables of the models are hand load, paramedic's weight and back sagittal flexion (Table 6).

4. Discussion

Previous research on stretcher loading/unloading activities had found a high risk of injury, as reported in companies' records of analysis of accidents and adverse events (Massad et al., 2000; Wang et al., 2009). Biomechanical analysis showed a peak back compression value of up to 3.9 kN while initiating lifting of the stretcher in a controlled laboratory setting (Cooper and Ghassemieh, 2007); meanwhile, high peak amplitudes and velocities of trunk bending were observed during field measurement (Prairie and Corbeil, 2014). In the field study reported on here, 71% of the 175 loading stretcher activities were considered at risk based on the compression criterion limit (≥3.4 kN; Waters et al., 1994). When considering various field contexts of stretcher loading and individual/team strategies, the variance in compression forces was mainly explained by hand load, paramedic's weight and some postural variables.

Compression forces during the majority of stretcher loadings into the ambulance exceeded the safe limits. Although none of the observed situations caused an injury, the results showed that paramedics are inevitably at risk of injury while performing this task. To our knowledge, this is the first field study of paramedics that has shown such critical results, which are even more alarming than the findings in a simulated work situation with a manual stretcher system (Cooper and Ghassemieh, 2007). However, in Cooper and Ghassemieh's experiment, trained ambulance workers executed the loading in teams with a different stretcher system and they did not place extra equipment on the stretcher. Furthermore, the lifting was done in a weather- and humidity-controlled environment and on firm, level ground. Real tasks performed by paramedics involve many different work situations including different

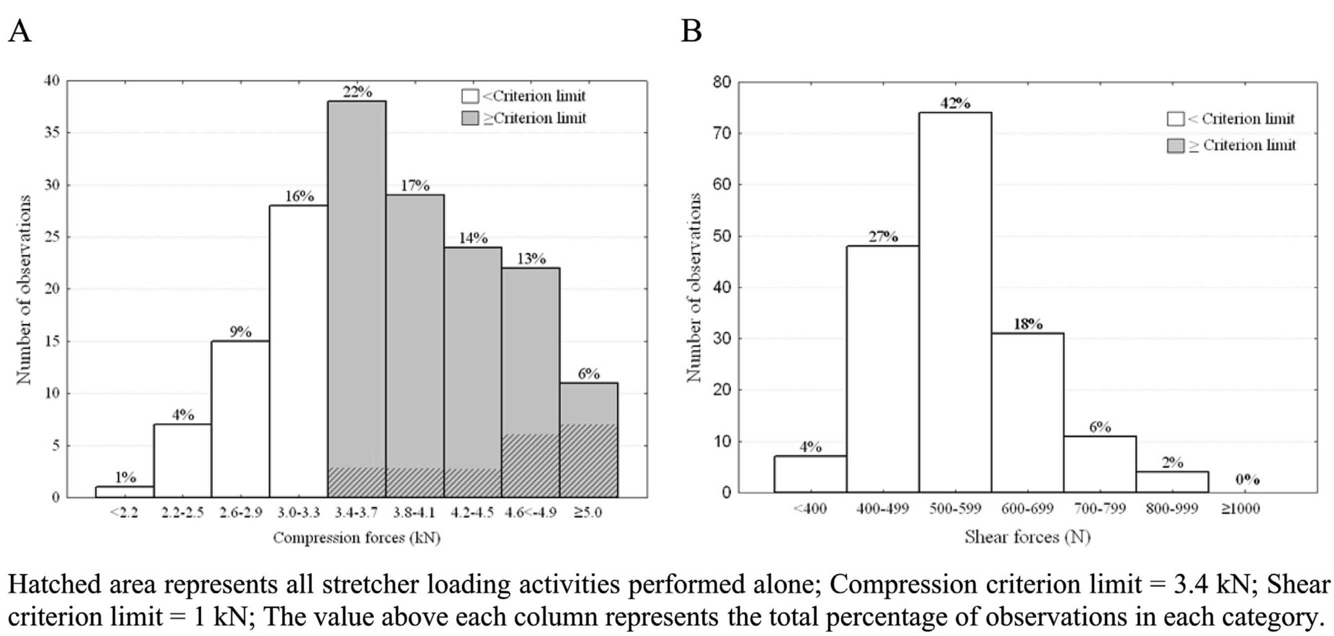

Fig. 5. L5/S1 back compression (A) and shear forces (B) experienced by ambulance workers while loading a hydraulic stretcher.

Table 5
Multiple regression analysis models predicting compression force at L5/S1 during hydraulic stretcher loading.

Variables	Step in	Beta	B	R^2	R^2 change	F-value	*p*-value
Hand load (N)	1	0.64	4.71	0.28	0.28	65.94	<0.0001
Back sagittal flexion (°)	2	0.78	62.38	0.60	0.32	136.70	<0.0001
Elbow angle (°)	3	−0.36	−19.67	0.74	0.14	93.40	<0.0001
Paramedic's weight (kg)	4	0.28	17.44	0.84	0.11	115.62	<0.0001
Shoulder angle (°)	5	0.29	30.26	0.88	0.04	49.60	<0.0001
Hip angle (°)	6	0.14	10.91	0.90	0.02	28.39	<0.0001
Knee angle (°)	7	−0.10	−7.71	0.91	<0.01	16.63	<0.0001
Paramedic height (cm)	8	0.15	13.23	0.92	<0.01	16.86	<0.0001
Gender[a]	9	0.10	193.70	0.92	<0.01	10.96	<0.01

Forward stepwise regression; n = 175; β = regression coefficients; Beta = standardized coefficients; standard error of the estimate ± 243 N; Intercept = −2350 N; R^2 of model = 0.92; significance level of model p < 0.0001.
[a] Man = 0, Woman = 1; $Compression\ force = \sum_{i=1}^{9} \beta_i * Variable_i + Intercept$.

Table 6
Multiple regression analysis models predicting shear force at L5/S1 during hydraulic stretcher loading.

Variables	Step in	Beta	β	R^2	R^2 change	F-value	*p*-value
Hand load (N)	1	0.77	0.69	0.52	0.52	185.59	<0.0001
Paramedic's weight (kg)	2	0.40	3.04	0.81	0.29	257.04	<0.0001
Back sagittal flexion (°)	3	0.35	3.42	0.94	0.14	398.23	<0.0001
Gender[a]	4	−0.14	−33.17	0.97	0.03	133.10	<0.0001
Hip angle (°)	5	−0.09	−0.81	0.98	<0.01	55.06	<0.0001
Knee angle (°)	6	0.06	0.50	0.98	<0.01	25.08	<0.0001
Paramedic's height (cm)	7	0.04	0.45	0.98	<0.01	6.76	0.01
Shoulder angle	8	0.03	0.34	0.98	<0.01	4.13	0.04

Forward stepwise regression; n = 175; β = regression coefficients; Beta = standardized coefficients; standard error of the estimate ± 15 N; Intercept = −110 N; R^2 of model = 0.98; significance level of model p < 0.0001.
[a] Man = 0; Woman = 1; $Shear\ force = \sum_{i=1}^{8} \beta_i * Variable_i + Intercept$.

ground surfaces and inclines, patient morphology, climate/environmental conditions, etc. All these factors may influence postural control during the loading activity, and therefore internal loading on the spine. Moreover, our observations were made with a more recent hydraulic stretcher system. Compression forces reported in this study took most of these variations into account, and the study demonstrated that in many work situations, paramedics' back compression exceeded the safe loading levels.

4.1. Hand load

Stretcher weight, patient weight, equipment weight and position on the stretcher, and teamwork influenced the hand load during stretcher loading. Loading the stretcher alone instead in a team should be prohibited, as this strategy considerably increases the hand load and consequently the internal load on the paramedic's spine. This result emphasizes the importance of teamwork in the paramedic profession; many studies had already shown its importance while transporting patients (Arial and Benoit, 2011; Arial et al., 2009; Corbeil and Prairie, 2012; Duval et al., 2009). The decision to load the stretcher into the ambulance alone or as a team is made by the two paramedics together and could result in a practice disagreement. The decision to lift a stretcher alone may represent a habit developed with earlier stretcher model systems. For instance, one former stretcher system required one paramedic to lift and push the stretcher while his or her teammate raised the stretcher's wheels by hand. In comparison, the hydraulic stretcher was designed to be loaded by a team and incorporates an electric mechanism to raise (or lower) the wheels automatically. A significant reduction in the relative incidence of injury was seen following the implementation of electrically powered stretchers (Studnek et al., 2012). However, this new design (Stryker Power-PRO™ XT model = 56.7 kg) increases the stretcher's total weight compared to common models (Stryker Performance-PRO™ XT model = 40.0 kg; Stryker MX-PRO™ R3 = 38.0 kg; Ferno 35X PROFlexx model = 42.0 kg), thereby increasing the weight to be lifted by the paramedics. New designs should consider decreasing stretcher weight.

The patient's weight directly affected the load lifted by the paramedics. While it is impossible for paramedics to refuse to transport a patient for that reason, a solution would involve positioning the patient appropriately on the stretcher. Indeed, paramedics' hand load and the reaction force of the wheels on the retractable head section of the stretcher depend on where the patient's center of mass is located on the stretcher. A patient installed closer to the ambulance end will increase the mechanical advantage of the levers, and therefore decrease hand force. This is easiest to do when the patient is installed on the stretcher in a lying position (still, it depends on the patient's height and initial position on the stretcher). However, if the head of the stretcher is inclined, it is impossible to install the patient closer to the ambulance end. In addition, the mechanical advantage of a class-two lever (i.e., the load is between the pivot and the effort) is applicable for all equipment installed on the stretcher. Therefore, it would be advisable to place – and only if necessary – the oxygen tank, first aid bags and monitor in position 4, where the lever is the shortest.

Based on the L5/S1 compression force equation predicted by the regression analysis (Table 5), mathematical simulations were performed to predict the influence of stretcher-ambulance contact point position and stretcher weight on compression force for all 175 loading activities. Simulation parameters (distance and/or weight) were varied by increments of 10% and the outputs of the simulations made it possible to assess hand force, compression force at L5/S1 and percentage of loading activities that exceeded the compression criterion limit. Interestingly, a reduction in the magnitude of both parameters yielded a significant reduction in the number of loadings at risk of injury (i.e., exceeding the safe loading level), but a greater effect was observed when the stretcher-ambulance contact point was reduced (Table 7). This reduction in

Table 7
Percentage of the 175 loading activities with compression force exceeding the compression criterion limit determined from mathematical simulations using the forward stepwise model predicting compression forces at L5/S1.

Simulation parameters		Mean hand force ± SD (N)	Mean compression force ± SD (N)	Percentage of loading with compression force > 3400 N (%)
Wheel position* (% of actual value)	Stretcher weight (% of actual value)			
100	100	392 ± 118	3692 ± 805	64.0
90	100	353 ± 98	3507 ± 776	54.9
80	100	304 ± 88	3276 ± 744	45.1
70	100	245 ± 69	2979 ± 712	28.0
100	90	373 ± 108	3600 ± 792	60.0
100	80	353 ± 98	3508 ± 781	55.4
100	70	333 ± 98	3417 ± 770	52.0
90	90	333 ± 98	3421 ± 766	51.4
80	80	275 ± 78	3120 ± 729	37.7
70	70	196 ± 59	2776 ± 697	17.1

*Change in the position of the wheels on the retractable head section of the stretcher. Note that a change in the wheels' position changes all the lever arms; SD = Standard deviation.

distance could be achieved if either the contact point for the stretcher's head-end wheels or the fastener system in the ambulance was designed differently.

These biomechanical solutions will reduce the effort exerted by paramedics to load the stretcher into the ambulance, as well as the compression and shear forces on their backs. Another solution would be for the paramedics to call a backup team to help execute the task when another team is available. This organizational solution was observed on a few occasions during the field capture but was not included in the data analysis. Both biomechanical and organizational solutions should be considered to reduce physical exertion while loading a stretcher into an ambulance.

4.2. Weight of the paramedic

A recent study of manual material handling demonstrated that being overweight is associated with an increase in lumbar load (Corbeil et al., 2013). High body mass intensifies the moment force on the vertebrae and consequently the risk of musculoskeletal injury. The present study also found that paramedics' body weight has an important influence on back compression force.

As recent studies of paramedics have highlighted (Hegg-Deloye et al., 2013; Tsismenakis et al., 2009), obesity markedly increases the risk of cardiovascular disease, musculoskeletal injury, obstructive sleep apnea and socioeconomic consequences. Among the paramedics in the present study, 50% were considered overweight or obese. This is in line with a recent study that reported a high prevalence of overweight in paramedic recruits (Tsismenakis et al., 2009). Therefore, a preventive approach based on weight control, especially for overweight and obese paramedics, should be addressed in future studies.

4.3. Postural variables

The compression forces experienced by the lower back are highly posture-dependent (Cooper and Ghassemieh, 2007). The average back sagittal flexion position of 32° we found in this study when the stretcher-patient is about to be lifted is in accordance with the back flexion position while loading/unloading the stretcher patient reported in another field study (Prairie and Corbeil, 2014). Back sagittal flexion was the most important postural predictor of compression and shear force variations at L5/S1. Increased elbow, shoulder and/or back sagittal angles from their anatomical position results in an increase of the moment arm at L5/S1, and the moment arm directly affects the load applied at L5/S1 (Chaffin et al., 2006). Keeping the arm and forearm close to the body and the back straight reduces the moment arm and the compression forces on the back. Stretcher and ambulance designs have a direct influence on the posture adopted by paramedics at the onset of stretcher lifting. A study demonstrated that stretchers' design features (weight, shape and positioning of handles, and height adjustment mechanism) influence back and shoulder muscle strain (Kluth and Strasser, 2006). These authors suggest that smaller (female) paramedics are disadvantaged. Results of the regression analysis models of the present study suggested that smaller (female) and taller paramedics experienced increased compression force at L5/S1 when loading the stretcher, which could be partly explained by the fixed positioning of the stretcher handles. Paramedics would benefit from better training on how to reduce the moment arm at the back while loading a stretcher. The design of the stretchers used while loading as a team could also be revisited to ensure that paramedics can minimize awkward postures, especially by paying particular attention to their backs.

4.4. Limitations of the study

The results obtained with 3DSSPP are based on the assumptions that the movements being studied are static or very slow and that the hand force is oriented vertically. Consequently, the influence of acceleration, the effects of inertia and a simultaneous push/pull force component were ignored in the calculation of back compression and shear force, and this may tend to underestimate the real forces on the joints and muscles (Chaffin et al., 2006). But these simplifying assumptions were necessary in order to deal with the technical and environmental challenges of collecting data in a large set of work tasks performed in real-life situations without interfering with the paramedics' job. As others have demonstrated in previous studies (Cooper and Ghassemieh, 2007), it is expected that using the 3DSSPP software should still give a reasonable evaluation of the back compression and shear forces for the L5/S1 intervertebral disc.

One issue that was not examined is the fact that asymmetric loading causes unequal load distribution on the back and increases compression and shear forces (Marras et al., 1995). Asymmetric parameters were not evaluated in this study.

The way paramedics cooperate and share the forces during loading operations significantly affects the risk (Cooper and Ghassemieh, 2007). Use of a synchronization signal represents a team lifting strategy, aimed to optimize force sharing between teammates, and thus was not considered in this study. Unsynchronized force production by paramedics may result in imbalanced load distribution among them; in other words, one may support more of the load than the other (Barrett and Dennis, 2005). Barrett and Dennis (2005) reviewed the ergonomic issues affecting team lifting and concluded that future studies should examine how effort and load are distributed among lifting team members, with an emphasis on identifying factors that may increase the risk of injury.

Patients' weight was self-reported in 60% of cases; all other situations represented emergency calls where paramedics estimated the weight because the patient's health condition did not permit self-reporting. Shields et al. (2011) observed that people tend to underestimate their own weight in self-reporting. That being the case, the weights of the patients used in this study could actually have been higher.

Paramedics wore a recent version of Plamondon et al.'s (2007) back measurement system on their backs like a knapsack. The data collected with this equipment are not presented in this article. However, even though it weighs less than 3 kg, a measurement system carried on the back could influence the paramedics' work movements (Marras et al., 2010).

5. Conclusion

The aim of this research was to measure the risk of musculoskeletal disorders of the back using compression and shear force criterion limits during field loading of hydraulic stretchers into ambulances. Surprisingly, the great majority of the loading activities observed on the job and analyzed exceeded the compression force criterion limit at the L5/S1 joint. The most important compression force predictors were hand load, back sagittal flexion, elbow flexion, paramedic's weight and shoulder elevation.

Hand load has the highest impact on compression force and was principally influenced by teamwork and the weight of the stretcher and patient. Preventive measures must be formulated and applied to reduce the risk of back musculoskeletal disorders during the loading of stretcher patients. The following recommendations are drawn from the conclusions of this study:

- Design changes could be made to stretchers to limit the risk of injury to paramedics during loading. These changes could include:
  - Reducing the distance between the stretcher contact point on the ambulance floor and the end of the stretcher (different fastener system in the ambulance and/or the stretcher's head-end wheels).
  - Reducing the mass of hydraulic stretchers.
- Hydraulic stretchers must be lifted in teams of two paramedics every time, unless this is impossible.
- Paramedics should pay attention to where they position the equipment and the patient on the stretcher.
- Paramedics would benefit from better training on how to reduce back sagittal flexion and keep their hands close to their body while loading stretchers.
- Overweight and obese paramedics would benefit from losing weight in order to reduce internal loads during lifting activity.

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