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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:

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

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

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