Thoracolumbar junction injuries after rollover crashes: difference between belted and unbelted front seat occupants

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Received: 29 March 2009 / Revised: 21 July 2009 / Accepted: 4 August 2009 / Published online: 18 August 2009
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Abstract Motor vehicle collision (MVC) is one of the most common causes of thoracolumbar junction (TLJ) injury. Although it is of no doubt that the use of seatbelt reduces the incidence and severity of MVC-induced TLJ injury, how it is protective for front-seat occupants of an automobile after rollover crashes is unclear. Among 200 consecutive patients with a major TLJ (Th11-L2) injury due to high-energy trauma admitted from 2000 to 2004, 22 patients were identified as front-seat occupants of a four-wheel vehicle when a rollover crash occurred. The 22 patients were divided into two groups: 10 who were belted, and 12 who were unbelted. Patients' demographics including the mean Injury Severity Score (ISS), incidence of neurologic deficit, level of TLJ injury, and type of TLJ injury according to the AO fracture classification were compared between the two groups. Neurologic deficit was present exclusively in the unbelted group, and the difference in the incidence was statistically significant ($P = 0.04$). Similarly, AO type B/C injury was present exclusively in the unbelted group. The belted group had a significantly lower mean ISS than the unbelted group ($P < 0.01$). Comparison between the ejected and non-ejected victims within the unbelted group revealed no statistical difference in the incidence of neurologic deficit or type of injury. It is likely that the high incidence of

neurologic deficit in the unbelted group was due to the high incidence of AO type B/C injury. This study indirectly proves the efficacy of seatbelt in reducing the severity of rollover-induced TLJ injury. Because of the limited number of cases, it is uncertain whether ejection from vehicle, which occurs exclusively in the unbelted victims, is a crucial factor in determining the severity or type of injury after rollover crashes.

Keywords Thoracolumbar junction · Rollover crash · Seatbelt · Neurologic deficit

Introduction

Motor vehicle crash (MVC) is one of the leading causes of spine injury in many developed countries [7, 9]. It is of no doubt that the proper use of seatbelt by automobile occupants reduces the incidence of MVC-induced spine injury [1–5, 8, 10, 15–17]. Historically, seatbelt has been developed to afford maximal protection against frontal or rear-ended collision [6, 10], however, and it is relatively unknown how it protects the spine of automobile occupants from other types of crashes. Recently, epidemiologic studies found that rollover crashes are associated with the unusually higher incidence of spine injury, compared with frontal crashes [13, 14]. There have been few clinical data on spine injury after rollover crashes in the medical literature. We have been investigating relationship between the seatbelt use and MVC-induced thoracolumbar junction (TLJ) injury [11], and in the present study, we attempt to evaluate the efficacy of seatbelt against TLJ injury after rollover crashes, by analyzing how the incidence of neurologic deficit and radiographic type of TLJ injury differs between automobile front-seat occupants who were belted

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and those who were unbelted at the time of rollover crashes.

Materials and methods

Two-hundred consecutive patients with major TLJ (Th11–L2) injury, excluding isolated transverse process, pedicle, or laminar fractures, were admitted to Tampa General Hospital, a regional Level I trauma center, after sustaining high-energy trauma between January 2000 and March 2004. Among the 200 patients, 22 patients with a major, but non-fatal TLJ, injury were identified either as drivers or front-seat passengers of a four-wheel automobile including sedans, wagons, sport-utility vehicles (SUVs), mini-vans, and pick-up trucks, when a rollover accident occurred. Victims of frontal or side vehicular crashes were excluded: another 39 patients with TLJ injury associated with frontal crashes had already been presented elsewhere [11] and are not described here. Medical records, radiographic images, and reports of the 22 patients were reviewed thoroughly, and they were divided into two groups: 10 who were belted with three-point restraint and 12 who were unbelted at the time of the crash. The information regarding whether the victims were belted, unbelted or ejected from an automobile came either from paramedics or the victims themselves. We collected and analyzed the data exclusively from front-seat occupants of a four-wheel vehicle: data from rear-seat passengers were excluded intentionally, because mechanism of injury may be substantially different between front- and rear-seat passengers, and the latter might have worn a lap belt (two-point restraint system), the use of which may confound the objective of this study. Patients' demographics including mean Injury Severity Score (ISS), type and level of TLJ injury, and the incidence of neurologic deficit on admission were evaluated and compared between the two groups. Student's *t*-test and Fisher exact probability test were used for statistical analysis. Probability less than 0.05 was considered statistically significant.

Results

Demographics

The demographic data of the 22 patients are shown in Table 1. There were eight males and two females in the belted, and six males and five females in the unbelted group, respectively. Eight of the 12 unbelted patients were found to be ejected from a vehicle. The percentage of female was lower in the belted compared with the unbelted group (20.0 vs. 50.0%), although the difference was not statistically significant ($P = 0.20$). The mean age was 36.3 ± 3.4 years for the belted (range: 18–52 years) versus 31.8 ± 4.0 years for the unbelted group (range: 17–64 years). The unbelted group trended to be younger, but the difference was not statistically significant ($P = 0.10$). Associated bodily injury was present in 5 vs. 10 (50.0 vs. 83.3%) of the belted and unbelted group, respectively. The difference was not statistically significant ($P = 0.17$). In the belted group, the most common associated injuries were rib fracture and hip fracture, that were present in 2 and 2 patients (20.0 and 20.0%), respectively. In the unbelted group, the most common associated injuries were pelvic fracture and long bone fracture of the extremities, that was present in 5 and 5 patients (41.7 and 41.7%), respectively. Splenic and/or liver laceration, traumatic brain injury, and pulmonary contusion were also common, that was present in 3, 2, 2 and 2 patients (25.0, 16.7, 16.7, and 16.7%), respectively. Eight out of the 10 unbelted victims sustained multiple associated bodily injuries. Mean ISS was 14.8 ± 1.9 for the belted versus 33.8 ± 3.3 for the unbelted group. The unbelted group had a higher ISS, and the difference was statistically significant ($P < 0.01$).

Level of TLJ injury

The anatomical level of TLJ injury in each group is shown in Fig. 1. In the belted group, injury occurred at T11 in one, at T12 in three, at L1 in five, and at L2 in two patients. One patient had contiguous TLJ compression fracture (at T11

Table 1 Demographics of 22 patients with rollover-induced TLJ injury

Group	N	M:F	Mean age (y)	Associated bodily injury ^a	Mean ISS
Belted	10	8:2	36.3 ± 3.4	In 5 patients (50.0%): 2 rib fx, 2 hip fx, 1 cervical spine fx, 1 pulmonary contusion	14.8 ± 1.9
Unbelted	12	6:6	31.8 ± 4.0	In 10 patients (83.3%): 5 pelvic fx, 5 long bone fx, 3 spleen lac, 2 liver lac, 2 TBI, 2 pulmonary contusion, 2 rib fx, 1 scapular fx	33.8 ± 3.3
<i>P</i>		0.20	0.10	0.17	<0.01**

Fx fracture, *ISS* Injury Severity Score, *lac* laceration, *MVC* motor vehicle collision, *TLJ* thoracolumbar junction

^a Because of the presence of multiple trauma patients, a total sum of the associated bodily injuries exceeds the number of patients

** Statistically significant

Fig. 1 A bar graph showing the anatomical distribution of the thoracolumbar junction (T11–L2) injury caused by rollover crashes

and T12). In the unbelted group, injury occurred at T11 in three, at T11/12 intervertebral level in three, at T12 in four, at L1 in one, at L1/2 intervertebral level in one, and at L2 in one patient. One patient had non-contiguous TLJ compression fracture (at T12 and L2).

Neurologic deficit

Among the belted group, no patients showed neurologic deficit. Among the unbelted group, five patients (41.7%) showed neurologic deficit. Four patients had American Spinal Injury Association Injury Scale (ASIA) Grade-A deficit, and the other had ASIA Grade-B deficit. Apparently, neurologic deficit was present exclusively in the unbelted group, and the difference in the incidence was statistically significant ($P = 0.04$) (Fig. 2).

Radiographic classification of TLJ injury

In all patients, both radiograph of the TLJ and helical computed tomography (CT) scan with sagittal/coronal reconstitution were performed routinely. All radiographic images were read by board-certified radiologists, and they were classified either as type A (compression or burst fracture), type B (flexion-distraction injury), or type C (rotation injury) according to the AO fracture classification by Magerl et al. [12]. In cases where the type of TLJ injury could not be accurately determined from the charts, images were reviewed by one of the authors (JI). In the belted group, all 10 patients were diagnosed with a type A injury, and therefore, there were no patients with a type B/C injury. Compression and burst fracture was present in 5 and 5 patients, respectively. In the unbelted group, type A, B, and C injury was present in 8, 1, and 3 patients, respectively. Among the eight patients with a type A injury, three

Fig. 2 A bar graph showing the incidence of neurologic deficit in rollover-induced thoracolumbar junction injury. The incidence was significantly lower in the belted group compared with the unbelted group ($P = 0.04$)

had a burst fracture and the other five had a compression fracture. AO type B/C injury (four cases) was present exclusively in the unbelted group, although the difference in the incidence was not statistically significant (0% in the belted vs. 33.3% in the unbelted, $P = 0.10$) (Fig. 3). All of the four patients with a type B/C injury in the unbelted group had neurologic deficit.

Ejected versus non-ejected victims

Among the unbelted group, the eight patients who were ejected from automobile had a higher ISS compared with

Fig. 3 A bar graph showing the frequency of fracture type in rollover-induced thoracolumbar junction injury. The frequency of AO type B/C injury trended to be lower in the belted group compared with the unbelted group ($P = 0.10$)

the four who were not ejected (34.4 ± 4.2 vs. 22.3 ± 3.9), although the difference was not statistically significant ($P = 0.14$). Similarly, neurologic status on admission was compared between the ejected and the non-ejected subgroup. Three of the eight (37.5%) ejected and two of the four (50.0%) non-ejected patients had neurologic deficit. The difference was not statistically significant ($P = 0.84$). Type of TLJ injury was also compared between the two subgroups. Among the eight ejected victims, two (25.0%) had a type B/C injury, whereas among the four non-ejected victims, two (50.0%) had a type B/C injury. The difference was not statistically significant ($P = 0.55$). The results are summarized in Table 2.

Discussion

MVC is one of the most common causes of TLJ injury, although the great majority of MVC-induced spine injury involves the cervical spine [15]. After MVC, there is of no doubt about the seatbelt efficacy in reducing the incidence and severity of spine injury. In a study of 3,927 injured front-seat occupants involved in two-car crashes, the incidence of cervical spine fractures in the restrained group was one-third of that of the unrestrained group [4]. Although authors agree that seatbelt is most protective for the cervical spine [4, 5], its efficacy against TLJ injury is less known. Probably, the efficacy of seatbelt in reducing MVC-induced TLJ injury may be less prominent compared with that in cervical spine injury. Seatbelt has historically been designed and developed to be protective against frontal or rear-ended collision, rather than the rollover crash [6, 10]. Despite recent reports that rollover crashes are associated with a significantly higher incidence of spine injury compared with frontal crashes [13, 14], few studies have focused on TLJ injury after rollover crashes. Rollover is a crash involving vehicle rotation of at least one-quarter turn about a lateral or longitudinal axis [6]. Vehicle movement during rollover involves deceleration along a horizontal plane, vertical acceleration and deceleration, and rotational acceleration and deceleration. As a result, rollover results in complex occupant kinematics with the potential for critical injuries [6].

Table 2 Comparison between ejected versus non-ejected victims within the belted group

Group	ISS	Neurologic deficit (+)	AO type B + C
Ejected ($N = 8$)	34.4 ± 4.2	3 (37.5%)	2 (25.0%)
Non-ejected ($N = 4$)	22.3 ± 3.9	2 (50.0%)	2 (50.0%)
<i>P</i>	0.14	0.84	0.55

ISS Injury Severity Score

The results of the present study that the unbelted front-seat occupants had a significantly higher incidence of neurologic deficit and tendency of sustaining AO type B/C injury is reasonable, because the unbelted occupants are far more likely to undergo a combination of axial, translational and rotation forces at the time of rollover, resulting in flexion-distraction or rotation TLJ injury. The higher ISS and higher incidence of associated bodily injury in the unbelted group also implies that they went through more violent traumatic forces than the belted group. All patients with type B/C injury had neurologic deficit, and the increased neurologic injury severity in the unbelted group is obviously due to the increased number of patients with type B/C injury (Figs. 2, 3).

During rollover crashes, bodily injuries may be caused either by multiple contacts with the vehicle interior, direct compression by the intrusion, or by ejection [6, 13, 14]. There was a marked difference in the severity and anatomical distribution of bodily injuries between the belted and unbelted group. Critical bodily injuries such as pelvic fracture or visceral laceration were seen almost exclusively in the unbelted group. Most bodily injuries in the belted group were not life-threatening. Rib fracture or lung contusion, often seen in the latter, may be the result of strangulation by the shoulder belt.

Interestingly, all of the 10 belted occupants had a type A injury, either compression or burst fracture, despite the presence of rotational injuring vector during rollover crashes. The reason is unclear, but axially compressive forces at the time of the automobile's final landing to the ground may be one of the responsible mechanisms of injury. The results are similar to those in the victims of frontal crashes which we had reported earlier, in whom type A injury was the most common TLJ injury in the belted population [3, 10, 11]. Mechanism of MVC-induced TLJ injury in the belted automobile occupants needs further laboratory, i.e., biomechanical, evaluation, regardless of type of automobile crashes.

Regarding the comparison between ejected versus non-ejected victims within the unbelted group, it is expected that the ejected victims sustain more critical bodily injuries. In fact, their associated bodily injuries tended to be more severe compared with the non-ejected counterpart. There was no significant difference in the injury severity, however, between the two subgroups. Similarly, there was no significant difference in the type of injury, as represented by the incidence of AO type B/C injury. These findings suggest that ejection per se may not be a crucial factor in determining the neurologic status or injury type in rollover-induced TLJ injury. The reason is unclear, but in many unbelted victims, critical TLJ injuries may have been completed at the time of impact rather than after ejection from vehicle. Because of the limited number of cases,

however, it is premature to conclude that ejection is *not* a crucial factor in determining the neurological deficit severity or the type of injury.

There are several limitations in this study: it is impossible to know whether the belted group had actually a lower incidence of TLJ injury after rollover crashes, because of the study's retrospective nature. None of the critical factors that influence the severity of spine injury after rollover crashes, including velocity of vehicle at the time of crash, degree of deceleration, number of vehicle's quarter turns, type of rollover (trip over versus turnover versus fall over versus flip over), and type/weight of a vehicle were taken into account in this study, because there was often inadequate description in the charts regarding those information. Similarly, no evaluation was made regarding whether airbags had been deployed at the time of impact, also because of paucity of information. Comparison between the belted and unbelted occupants may be only valid if no other restraint system, particularly airbags, was also operative. Although the efficacy of airbags in conjunction with seatbelt against cervical spine injury has well been recognized, few studies have been performed on the efficacy of airbag against TLJ injury. Finally, many of the 22 patients were referred from emergency physicians after their condition had been stabilized after resuscitation. Those who sustained fatal associated bodily injuries might not have been referred to spine surgeons, and the frequency/severity of severe associated injuries might have been underestimated. It is noteworthy that SUVs have a significantly higher likelihood of spine injury compared with sedans, regardless of whether they are involved in rollover crashes or not [13, 14]. Rollover-associated spine injury is an important medico-social issue not only to spine surgeons, but also to automobile industries and general public, and accumulation of clinical and laboratory data is awaited.

In conclusion, the unbelted front-seat occupants had a significantly higher chance of sustaining severe TLJ injury after rollover crashes, compared with the belted counterpart. AO type B/C injury also occurred exclusively in the unbelted group, and the increased injury severity may be attributed to the increased incidence of type B/C injury.

Acknowledgments This paper had been presented orally at SPINEWEEK 2008 on 28/05/2008 (Geneva, Switzerland). No funds were received in support of this work. No benefits in any form have been and will be received from a commercial party related directly or indirectly to the subject of this manuscript.

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