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## **Descriptive analysis of the effect of back protector on the prevention of vertebral and thoracolumbar injuries in serious motorcycle accident**

Sanae Afquir, Anthony Melot, Amina Ndiaye, Emmanuelle Hammad, Jean-Louis Martin, Pierre-Jean Arnoux

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1 **TITLE :**

2 Descriptive analysis of the effect of back protector on the prevention of vertebral and  
3 thoracolumbar injuries in serious motorcycle accident

4

5 **AUTHORS :** Sanae Afquir <sup>a,b</sup>, Anthony Melot <sup>a,c</sup>, Amina Ndiaye <sup>d</sup>, Emmanuelle Hammad <sup>e</sup>,  
6 Jean-Louis Martin <sup>d</sup>, Pierre-Jean Arnoux <sup>b,c</sup>

7

8 **CORRESPONDING AUTHOR :** [sanae.afquir@gmail.com](mailto:sanae.afquir@gmail.com)

9

10 **AFFILIATIONS :**

11 (a) Laboratoire de Biomécanique Appliquée, UMRT24 AMU/IFSTTAR, Marseille, France

12 (b) iLab-Spine - Laboratoire international en imagerie et biomécanique du Rachis, Marseille,  
13 France

14 (c) Department of Neurosurgery, Trauma centre, Hôpital Nord, Marseille, France

15 (d) Unité Mixte de Recherche Epidémiologique et de Surveillance Transport Travail  
16 Environnement, UMRESTTE UMR T9405

17 (e) Department of anaesthesia and Intensive Care Units, Trauma centre, Hôpital Nord,  
18 Marseille, France

19 **ABSTRACT:**

20 **Context and objective:**

21 Among the different products and protective gear used by riders of two-wheeled motorized  
22 vehicles, back protectors that are designed to prevent damage to the spinal column are widely  
23 used today compared other protections. However, few studies measure their effectiveness.  
24 Can their effectiveness be measured? How do they help decrease or change the nature of  
25 thoracolumbar traumas that occur?

26 To address these questions and remedy the lack of objective data regarding these products, an  
27 epidemiological, clinical, and biomechanical analysis of motorcycle riders who were admitted  
28 to a French trauma center after an accident was performed.

29 **Method:**

30 A questionnaire was administered to victims of accidents involving two-wheeled motorized  
31 vehicles who were admitted to the trauma room at the Marseille trauma center over the course  
32 of 2016. Collect data are related to the victim, the accident scenario, and a detailed description  
33 of the observed injuries using AIS (Abbreviated Injury Scale) coding and Magerl  
34 classification. Univariate analyses and Fisher tests were performed for victims who were or  
35 were not wearing back protectors.

36 **Results:**

37 This study collected data from 124 victims. Almost half of the victims were wearing a back  
38 protector at the time of the accident (53 victims, thus 43% of riders). Collectively, twenty-  
39 nine victims who were wearing back protectors had 57 thoracolumbar injuries, and twenty  
40 eight victims who were not wearing back protectors had 75 thoracolumbar lesions. The results  
41 from this study show that there is no significant difference in the nature and mechanism of  
42 thoracolumbar injuries as a function of back protection. The majority of the thoracolumbar

43 injuries were not severe. They were primarily bone injuries, essentially compression fractures,  
44 regardless of whether a back protector was worn.

45 **Conclusion:**

46 This study shows that the use of back protection does not decrease the number, type, or  
47 mechanism of thoracolumbar injuries associated with accidents involving two-wheeled  
48 motorized vehicles. However, it suggests that lumbar vertebral injuries are deflected towards  
49 the thoracic vertebrae when back protectors are worn. Finally, it suggests that the design of  
50 back protectors should be reconsidered to better protect riders from what are referred to as  
51 compression fractures (craniocaudal force), which remain the primary form of fracture  
52 regardless of the rider's characteristics, based on the data analyzed.

53 **Keywords:** accident, two-wheeled motorized vehicle, severity, mechanism of injury, back  
54 protection, thoracolumbar spine.

55

56

57

## 58 1. Introduction

59 In 2016, 22% of users of two-wheeled motor vehicles (TWMVs) were the victim of an  
60 accident on public roads (Observatoire national et al., 2017), even though they only represent  
61 2% of road traffic (Van Elslande et al., 2014). Even more concerning, Blaizot et al. showed  
62 that riders of TWMVs have the highest rates of hospitalizations, serious injuries, and fatal  
63 injuries (Blaizot et al., 2013). Their vulnerability is explained in part by instability due to very  
64 limited contact with the ground (only two points of support), being difficult to see because of  
65 their small size, and of course the absence of a car body, which exacerbates their  
66 vulnerability. In 2016, results from the Rhône register revealed that 13% of victims of  
67 TWMV accidents in the Rhône region sustained at least one spinal injury (Observatoire  
68 national et al., 2017). Spinal trauma can be serious due to neurological consequences, which  
69 can be life-threatening or have a profound effect on the patient's functional prognosis, and  
70 their long-term complications.

71 To prevent this type of injury, back protectors have been designed to alleviate shocks to the  
72 thoracic and lumbar regions by covering the spine with a single plate or multiple articulated  
73 plates. As of 2003, back protectors must conform with norm EN 1621-2 entitled  
74 "Motorcyclists' Protective Clothing against mechanical impact – Part 2: Requirements and  
75 test methods for motorcyclists back protectors", which evaluates the ergonomics and the  
76 reduction in impact forces. These protectors must be able to withstand five impacts of 50  
77 joules each, two of which are delivered to points that are deliberately chosen for their  
78 apparent weakness (joints...) (*NF EN 1621-2 Vêtements de protection contre les chocs  
79 mécaniques pour motocyclistes - Partie 2: protecteurs dorsaux - Exigences et méthodes  
80 d'essai*, 2014).

81 In France, the use of back protectors is not required, and there are no figures available  
82 regarding the rate of back protector use. An analysis performed in Australia highlighted an

83 increase in the use of back protectors from 19% in 2001 to 44% in 2006 (de Rome, 2006).  
84 Despite an *a priori* increase in the rate of the use of back protectors, however, very few  
85 studies have been published that assess their effectiveness in TWMV accidents. Recently, a  
86 comparison of De Rome's article "Motorcycle protective clothing: Protection from injury or  
87 just the weather?" and Guistini's article "Use of back protector device on motorcycles and  
88 mopeds in Italy" showed that there is a lack of evidence regarding the effectiveness of back  
89 protectors with regards to spinal injuries (Ekmejian et al., 2016). According to Ekmejian,  
90 additional analysis is needed regarding the mechanisms of injuries to determine whether back  
91 protectors are more useful in specific circumstances. These results and analyses highlight the  
92 necessity of making precise clinical data available to complement biomechanical and  
93 epidemiological analyses.

94 AIS coding enables each injury to be coded by body region, anatomical structure, the type of  
95 injury, and the severity of the injury, with a predefined measure of the immediately associated  
96 severity. However, it does not indicate the mechanism of injury. At the level of the thoracic  
97 and lumbar spine, the Magerl classification system (Magerl et al., 1994) provides a  
98 classification of the lesions linked to the mechanisms of the injuries. This classification  
99 system covers three types of fracture: A, B, or C, each of which contains groups and  
100 subgroups. Type A corresponds to a compression mechanism. Type B corresponds to a  
101 mechanism involving distraction of posterior or anterior elements. Type C corresponds to a  
102 rotation mechanism in addition to the mechanisms already described. This type of  
103 classification system is very useful for studying the etiology of spinal lesions.

104

105 Given the lack of scientific evidence, it seemed timely to us to investigate the effectiveness of  
106 back protectors, including their ability to prevent specific mechanisms of thoracic and lumbar  
107 spinal injuries related to TWMV accidents. Thus, the objective of this study was to combine

108 epidemiological and biomechanical analyses of injury mechanisms to identify the  
109 effectiveness of back protectors in preventing vertebro-medullary injuries at the  
110 thoracolumbar level in TWMV users.

111

## 112 2. Materials and methods

113 In order to provide a wider view of the problem, this study combined information on the  
114 victims and their TWMV accidents, as well as detailed clinical data using AIS coding and the  
115 Magerl classification system. These data provide additional information regarding protective  
116 gear, the accident scenario, and vertebro-medullary injuries.

### 117 2.1 A specific questionnaire

118 A specific, anonymous, two-part questionnaire was distributed in the North Marseille Hospital  
119 trauma center. This questionnaire is dedicated to treating severe trauma patients, often with  
120 life-threatening injuries. Between 900 and 1000 patients per year are treated in this unit, of  
121 which between 400 and 500 are seen for trauma.

122 The first part of the questionnaire was filled out by the patients when conscious, or by an  
123 accident witness in the case of a loss of consciousness. This part collected information about  
124 the patient: age, sex, type of TWMV, level of experience, and protective equipment worn.  
125 This information enabled us to identify the characteristics of the severely injured TWMV  
126 user. This part also contained information regarding the accident: type of accident, estimated  
127 speed, and accident causes. This information enabled us to formulate an overall accident  
128 scenario type. Only one response was allowed per question, except for the question regarding  
129 the protective gear used.

130 The second part was filled out by the doctor and involved the medical evaluation, paying  
131 specific attention to injuries. The injuries were coded based on the “AIS 2005” injury scale

132 (AAAM, 2005), from level 1 to 6. In order to identify the mechanisms of thoracolumbar  
133 injury, each vertebral injury was classified according to the Magerl classification system. This  
134 enabled us to determine the stability of thoracolumbar spinal fractures and identify  
135 neurological risks, and was used to guide therapeutic decision-making. According to Amoretti  
136 et al., 55% of initial neurological problems are associated with type C fractures, 30% with  
137 type B, and 15% with type A (AMORETTI et al., 2013).

138

## 139 2.2 Data collection

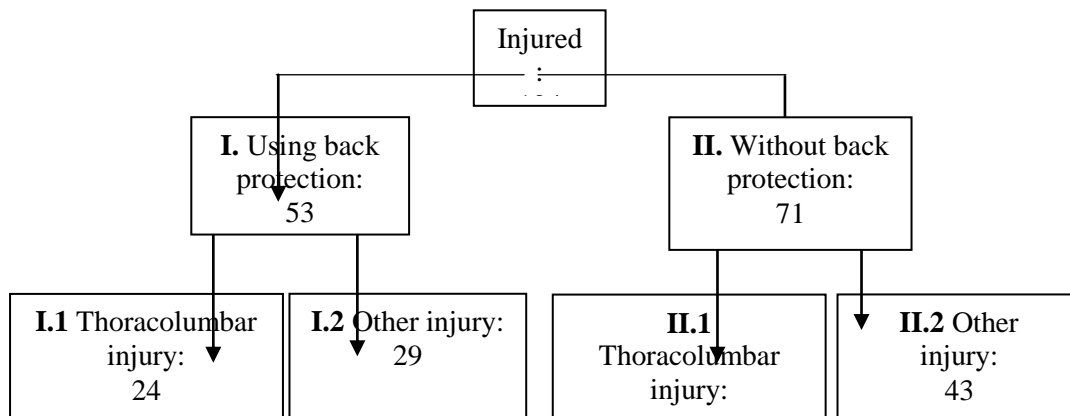
140 During 2016, all individuals who were in a road traffic accident involving a TWMV and who  
141 were treated in the emergency department at the Marseille trauma center were invited to fill  
142 out the specific two-part questionnaire. Consent for use of the collected data was requested at  
143 the end of each questionnaire. These data were used to construct a database containing 94  
144 variables that provided information about the victim and the accident and 20 variables for  
145 coding the lesions.

## 146 2.3 Study population

147 Based on the study objectives, the victims were classified into two groups: victims who were  
148 wearing back protectors (group I), and victims who were not wearing back protectors (group  
149 II). Each of these groups was then divided into subgroups based on whether or not they  
150 sustained thoracolumbar injuries (vertebro-medullary trauma): victims with thoracolumbar  
151 injuries (groups I.1 and II.1) and victims without thoracolumbar injuries (groups I.2 and II.2).  
152 The subgroups of individuals with thoracolumbar injuries were created based on the following  
153 criterion: each individual had at least one thoracolumbar injury with an AIS score of 1+. The  
154 subgroup of individuals without thoracolumbar injuries was created based on the following



155 criterion: the individual did not have any thoracolumbar injuries. The group selection process  
156 is summarized in Fig. 1.



157

158 *Fig. 1 Flow diagram of groups selection according to the use of back protection and trauma*

### 159 3. Statistical analysis

160 This was a prospective, descriptive study whose goal was to collect information regarding risk  
161 exposure and health events in the studied population. The analyses were performed in two  
162 steps.

163 First, univariate analyses and Fisher tests ( $p < 0.1$ ) were used to extract the individuals'  
164 characteristics. This first step consisted of comparing the groups of individuals with and  
165 without back protection (group I compared to group II) and the subgroups of individuals who  
166 had at least one thoracolumbar injury as a function of whether or not they were wearing back  
167 protectors (group I.1 to group II.1). The Fisher test assessed the equality of two distributions  
168 that were observed, without making any assumptions about the underlying reasons. The  
169 Fisher tests assessed the association between the following qualitative variables: sex, age,  
170 level of experience, cylinder size, type of road, protection used, type of accident, estimated  
171 speed prior to the accident, and death; and quantitative variables: thoracolumbar lesion and  
172 use of a back protector. These tests were performed for individuals who were wearing back  
173 protectors, and then individuals who had at least one thoracolumbar injury, respectively.

174 The second step focused on individuals who had at least one thoracolumbar injury (group I.1  
175 and II.1). The injuries suffered by each of the victims in these groups were coded using the  
176 AIS 2005 injury severity classification system and were then classified according to the  
177 Magerl AO classification system to determine the severity and injury mechanisms. The  
178 univariate analyses and Fisher statistical tests were performed using R Studio software.

### 179 3.1 Parameters studied:

180 The parameters studied were: sex, age, level of experience, TWMV cylinder size (<50 m<sup>3</sup>,  
181 between 50 and 125 m<sup>3</sup>, more than 125 m<sup>3</sup>), type of road (highway, avenue/boulevard/city  
182 street, country road), protective gear worn (helmet, jacket, neck protection, elbow pads,  
183 certified pants, gloves), type of accident, estimated speed, and finally consequences of the  
184 injury including death, as well as the injuries sustained according to the AIS 2005 injury  
185 severity scale and according to the Magerl classification.

186 For this analysis, three age groups (15-25, 26-39, 40-80) were defined based on the ages of  
187 individuals at risk of being involved in a TWMV accident (“ATSB. Monograph 12 –  
188 Motorcycle rider age and risk of fatal injury,” 2002). A comparison of accident victims and a  
189 reference population indicated that riders with less than 6 months of experience riding a  
190 TWMV of any type are more likely to be involved in an accident (7.8% compared to 5.2% for  
191 the reference group) (“MAIDS Étude approfondie sur les accidents en motocycles. Rapport  
192 final 1.3,” 2005). The level of the riders’ experience was therefore defined based on three  
193 levels: less than 6 months, between 6 months and 2 years, and more than 2 years. For helmet  
194 use, we distinguished between wearing a full-face helmet and wearing an open-face helmet.  
195 Two types of back protection were taken into account with no distinction: back protectors  
196 inserted into the jacket (integrated) and back protectors directly in contact with the back  
197 (separate). The types of accidents were grouped into five categories: single vehicle, with an  
198 obstacle, with a car, with a heavy vehicle, or with a motorcycle. Accidents “with obstacles”

199 included the following types: “safety barriers”, “building, wall, low wall, barrier”, or “narrow  
200 object (tree, post...)”. We defined three possibilities for estimated speed: fast, moderate, and  
201 slow. The “fast” group included speeds that were estimated to be “fast” and “too fast”, and the  
202 “slow” group included speeds that were estimated to be “stopped” and “slow”. The injury  
203 coding according to the Magerl classification system was obtained through two separate  
204 readings of computed tomography and/or MRI scans by radiologists and then spinal  
205 neurosurgeons. The thoracic vertebrae were classified into three groups depending on their  
206 positions in the spinal column: high thoracic vertebrae (from T1 to T4), middle thoracic  
207 vertebrae (from T5 to T8), and lower thoracic vertebrae (from T9 to T12).

## 208 4. Results

### 209 4.1 Characteristics of the injured subjects

210 In 2016, 124 individuals who were victims of a TWMV accident and who were admitted to  
211 the emergency department of the Marseille trauma center agreed to fill out a questionnaire.  
212 Most of these individuals were men (90% of victims), with a relatively large number of  
213 individuals aged 26 to 60 (59% of victims), riding at moderate speed (44% of victims), and  
214 with more than 2 years of experience (55% of victims). These users were well-equipped, with  
215 60% wearing a full-face helmet and 43% wearing back protection. The primary types of  
216 accidents were collision with a vehicle (48% of accidents) and falling off of the motorcycle  
217 (23% of accidents). There were 12 cases of fatal accidents (10% of victims) (Table 1).

218

219 Table 1: Characteristics of injured TWMV users. Dorso-lumbar injuries, sex, age, level of  
220 experience, displacement, type of road, protection, type of accident, estimated speed, death.

221

	I.Using back protection		II.Without back protection		Total (n=124) n (%)	Test Exact Fisher	
	I1.Dorso-lumbar injury (n=24) n (%)	I2.Other injury (n=29) n (%)	II1.Dorso-lumbar injury (n=28) n (%)	II2.Other injury (n=43) n (%)		Dorso-lumbar Injury (n=52)	Back protection (n=124)
	<b>Dorso-lumbar injuries</b>	57		75			132
<b>Sex</b>						1	0,3591
Female	2 (8,3%)	5 (17,2%)	2 (7,1%)	3 (7%)	12 (9,7%)		
Male	22 (91,7%)	24 (82,8%)	26 (92,9%)	40 (93%)	112 (90,3%)		
<b>Age</b>						0,213	0,468
15-25	12 (50%)	6 (20,7%)	7 (25%)	16 (37,2%)	41 (33,1%)		
26-60	5 (20,8%)	14 (48,3%)	8 (28,6%)	11 (25,6%)	38 (30,6%)		
>60	7 (29,2%)	9 (31,0%)	13 (46,4%)	15 (34,9%)	44 (35,5%)		
<b>Level of experience</b>						0,205	0,674
Less than 6 months	1 (4,2%)	5 (17,2%)	4 (25%)	4 (11,4%)	14 (11,3%)		
Between 6 months and 2 years	5 (20,8%)	5 (17,2%)	3 (18,8%)	9 (25,7%)	22 (17,7%)		
More than 2 years	18 (75%)	19 (65,5%)	9 (56,3%)	22 (62,9%)	68 (54,8%)		
<b>Displacement</b>						0,004	0,001
< 50m3	2 (8,3%)	3 (10,3%)	4 (25%)	7 (16,3%)	16 (12,9%)		
Between 50 and 125 m3	2 (8,3%)	4 (13,8%)	7 (25%)	10 (23,2%)	23 (18,5%)		
> 125m3	20 (83,3%)	22 (75,9%)	5 (17,9%)	17 (39,5%)	64 (51,6%)		
<b>Type of road</b>						0,404	0,684
Highway	3 (12,5%)	2 (6,9%)	1 (3,6%)	5 (11,6%)	11 (8,9%)		
City street	10 (41,7%)	15 (51,7%)	11 (39,3%)	17 (39,5%)	53 (42,7%)		
Country road	10 (41,7%)	11 (37,9%)	4 (25%)	12 (27,9%)	37 (29,8%)		
<b>Protection</b>						0,000	0,004
Full-face helmet	19 (79,2%)	27 (93,1%)	10 (35,7%)	18 (41,9%)	74 (59,7%)		
No full-face helmet	5 (20,8%)	1 (3,4%)	9 (32,1%)	18 (41,9%)	33 (26,6%)		
Jacket	17 (70,8%)	28 (96,5%)	0 (0%)	4 (13,8%)	49 (39,5%)		
Cervical protection	2 (8,3%)	0 (0%)	0 (0%)	0 (0%)	2 (1,6%)		
Elbow support	16 (66,7%)	28 (96,5%)	0 (0%)	8 (27,6%)	52 (41,9%)		
Motorcyclist's pants	6 (25%)	13 (44,8%)	1 (3,6%)	1 (3,4%)	21 (16,9%)		
Glove	9 (37,5%)	17 (58,6%)	6 (21,4%)	11 (37,9%)	40 (32,2%)		
<b>Collision</b>						0,157	0,521
No	6 (28%)	7 (24,1%)	6 (21,4%)	9 (20,9%)	28 (22,6%)		
Obstacle	2 (8,3%)	4 (13,8%)	3 (10,7%)	7 (16,3%)	15 (12,1%)		
Vehicle	11 (44%)	17 (58,6%)	13 (46,4%)	18 (41,9%)	60 (48,4%)		
Heavy vehicle	5 (20%)	1 (3,4%)	0 (0%)	3 (7%)	9 (7,3%)		
Motor	0 (0%)	0 (0%)	0 (0%)	2 (4,7%)	2 (1,6%)		
<b>Estimated speed before crash</b>						0,066	0,119
High	9 (37,5%)	10 (34,5%)	13 (46,4%)	19 (44,2%)	51 (41,1%)		
Average	15 (62,5%)	15 (51,7%)	9 (32,1%)	16 (37,2%)	55 (44,4%)		
Low	0 (0%)	2 (6,9%)	3 (10,7%)	5 (11,6%)	10 (8,1%)		
<b>Death</b>						0,199	0,674
No	23 (95,8%)	27 (93,1%)	23 (82,1%)	39 (90,7%)	112 (90,3%)		
Yes	1 (4,2%)	2 (6,9%)	5 (17,9%)	4 (9,3%)	12 (9,7%)		

#### 4.1.1 Characteristics of injured individuals as a function of back protection

The Fisher test did not show any significant difference in the number of riders who sustained a thoracolumbar spinal injury based on the use or non-use of back protection. Therefore, we cannot confirm that these two variables are dependent. The Fisher tests performed on the other qualitative variables listed showed that there was no confounding effect linked to use of back protection and sustaining a thoracolumbar spinal injury in this analysis.

Individuals who used back protection were more likely to ride a large-cylinder TWMV (79.2% of victims with back protection;  $p < 0.001$ ) and had a high rate of protective equipment use: 98% wore a helmet, 84% wore a jacket, 84% wore elbow pads, 36% wore certified pants, and 49% wore gloves ( $p < 0.004$ ); these riders also tended to be traveling at a “moderate” estimated speed just before the accident (57% of victims with back protection) and had a relatively low rate of fatality (6% of victims with back protection).

In contrast, individuals who did not use back protection exhibited a low level of protective equipment use: 24% of victims without back protection were not wearing any type of helmet, only 6% were wearing a jacket, 11% elbow pads, 3% certified pants, and 24% gloves; and tended to be traveling at a “fast” estimated speed just prior to the accident (45%).

The Fisher tests did not show any significant difference based of back protection for the following variables: sex, age, level of experience, type of road, type of accident, and death.

#### 4.1.2 Characteristics of individuals who sustained thoracolumbar injuries as a function of back protection

Groups I.1 and II.1 (I.1: individuals who sustained at least one thoracolumbar injury and who were wearing a back protector; II.1: individuals who sustained at least one thoracolumbar injury and who were not wearing a back protector) were distinguished by the rate of helmet use and the estimated speed. There was no significant different depending on the type of accident.

248 Group I.1 was composed of 24 individuals who had 57 injuries, for a rate of 2.4 injuries per  
249 individual. All of these individuals were wearing a helmet at the time of the accident ( $p <$   
250  $0.01$ ), and 63% estimated their speed just before the accident as “moderate” ( $p < 0.07$ ).

251 Group II.1 was composed of 28 individuals who had 75 injuries, for a rate of 2.7 injuries per  
252 individual. In total, 32% of these riders were not wearing a helmet at the time of the accident,  
253 and 46% estimated their speed as “fast” ( $p < 0.07$ ).

254

## 255 4.2 Nature and severity of thoracolumbar injuries

### 256 4.2.1 Nature of the injuries

257 Table 2 shows the nature of the thoracolumbar injuries as a function of wearing back  
258 protection. The majority of thoracolumbar injuries were strictly bone injuries. Among all  
259 injuries thoracolumbar, the transverse apophysis are the most affected. Out of the injuries  
260 sustained by victims who were wearing back protection, two were contusions of the spinal  
261 bone marrow. In contrast, no medullary lesions were found in victims who were not wearing a  
262 back protector. There are more burst injuries for victims without back protection. There is no  
263 significant difference between the number of injuries sustained by those who use back  
264 protection and those who do not use it ( $p$ -value = 7%).

265

266 Table 2: Description of the thoraco-lumbar injuries by the AIS 2005 coding according to the  
267 wearing of the back protector for the victims of a TWMV accident having had at least one  
268 thoraco-lumbar injury

Injury	I.Using back protection	II.Without back protection	Fisher
Transverse apophysis fracture	24	36	
Burst fracture	6	13	
Spinous process fracture	10	6	
Vertebral body fracture	6	4	

Multiple fractures of the same vertebra	5	5
Vertebral facet fracture	0	7
Fracture with or without dislocation, without involvement of the spinal cord	2	2
Spinal cord contusion	2	0
Pedicle fracture	1	1
Vertebral blade fracture	1	0
Unilateral dislocation of the facet joints	0	1
<b>Total</b>	<b>57</b>	<b>75 0,0688</b>

269

#### 270 4.2.2 AIS lesion severity and location

271 Table 3 shows the thoracolumbar injuries by location and AIS1+ and AIS3+ lesion severity as  
272 a function of wearing a back protector. The majority of the thoracolumbar injuries were  
273 classified as AIS2. Only six individuals who wore back protectors and six individuals without  
274 back protection had at least one injury classified as AIS3+.

275 In victims who had been wearing a back protector, there were proportionally more injuries in  
276 the high and medium thoracic regions (T1 to T8). Without back protection, there were  
277 proportionally more lesions in the lower thoracic (T9 to T12) and lumbar (L1 to L5) regions.

278 Among the individuals who had at least one thoracolumbar injury and had been wearing a  
279 back protector (group I.1), two individuals had both thoracic and lumbar spinal injuries.

280 Among the individuals who had at least one thoracolumbar injury and were not wearing back  
281 protection (group II.1), five individuals had both thoracic and lumbar spinal injuries.

282

283 Table 3 : Number of victims with at least one lesion by thoraco-lumbar location and by AIS  
284 score (AIS1 + and AIS3 +) according to the back protection wear: number and percentage.

	I. Using back protection		II. Without back protection	
	AIS1+	AIS3+	AIS1+	AIS3+
T1-T4	8 (33,33%)	1 (4,17%)	8 (28,57%)	0 (0%)
T5-T8	10 (41,67%)	1 (4,17%)	10 (35,71%)	1 (3,57%)
T9-T12	6 (25%)	1 (4,17%)	9 (32,14%)	2 (7,14%)
L1-L5	6 (25%)	3 (12,5%)	15 (53,57%)	3 (10,71%)

285 *Legend: Among those who were wearing back protection and injured in the thoraco-lumbar*  
 286 *region, 33.33% had at least one lesion in the T1-T4 region.*

287

288 **4.2.3 Mechanisms of thoracolumbar injuries according to the Magerl**  
 289 **classification system**

290 Table 4 shows the victims who had at least one thoracolumbar lesion by location and Magerl  
 291 classification as a function of wearing back protection. The majority of the victims sustained  
 292 at least one type A injury, which corresponds to axial compression. There were only slightly  
 293 more victims without back protection than with back protection who sustained at least one  
 294 type B or type C thoracic injury, corresponding to distraction or rotation, respectively: without  
 295 protection, five victims had at least one distraction injury and two victims had at least one  
 296 rotation injury; with back protection, two victims had at least one distraction injury and one  
 297 victim had at least one rotation injury. This difference was not significant.

298

299 Table 4: Number of victims with at least one AIS1+ lesion per thoraco-lumbar location in  
 300 function to the Magerl classification and back protection port: number and percentage.

	I.1 Using back protection			II.1 Without back protection		
	A	B	C	A	B	C
T1-T4	8 (33,33%)	1 (4,17%)	0 (0%)	8 (28,57%)	0 (0%)	1 (3,57%)
T5-T8	10 (41,67%)	0 (0%)	0 (0%)	7 (25%)	3 (10,71%)	0 (0%)
T9-T12	6 (25%)	0 (0%)	0 (0%)	6 (21,43%)	2 (7,14%)	1 (3,57%)
L1-L5	4 (16,67%)	1 (4,17%)	1 (4,17%)	14 (50%)	0 (0%)	0 (0%)

301 *Legend: Among those who were wearing back protection and injured in the thoracolumbar*  
 302 *region, 33.33% had at least one lesion in the T1-T4 region of type A (compression).*

303 **5. Discussion and limitations**

304 The originality of this study is that it combines an epidemiological analysis with a clinical and  
 305 biomechanical analysis to associate the nature of the injury with the mechanism that is likely



306 to have produced it. This study provided a description of severe injuries sustained after a  
307 TWMV accident and allowed us to quantify the severity and mechanisms of the  
308 thoracolumbar injuries as a function of using back protection.

### 309 5.1 Data collection:

310 For this study, we chose to recruit victims of TWMV accidents who were admitted to the  
311 emergency department between January 1, 2016 and December 31, 2016 and who agreed to  
312 fill out a questionnaire. Thus, a sample size calculation was not performed. The inconclusive  
313 Fisher tests could therefore be because of the lack of statistical significance due to including  
314 too few subjects. Thus, there could be a small significant difference that the small sample size  
315 did not allow us to detect.

316

317 Even though it was based on a relatively small sample, the objective of this study was to  
318 provide an exhaustive database. It did not take into account individuals who were involved in  
319 a TWMV accident but who were not injured or who only sustained non-severe injuries that  
320 did not require treatment in the trauma room. This could include individuals for whom  
321 protective gear, including back protection, was effective. In 2015, according to the Rhône  
322 register, 9.2% of victims of TWMV accidents were treated in the trauma room (161 out of  
323 1771 cases), and 17% of these individuals had at least one thoracolumbar injury (27 out of  
324 162 cases).

325 Given the nature of the traumatic injuries that we encountered, the responses to the first part  
326 of the questionnaire (information about the victim and how the accident happened) are most  
327 likely somewhat imprecise with regard to the trauma encountered. The patients were victims  
328 of a serious accidents, which are sometimes associated with memory problems, and this  
329 almost certainly led to a reduced response quality. In addition, this part of the questionnaire  
330 was filled out by the patients when they were able to, or by a witness to the accident when the

331 patient was unconscious or disoriented. According to the doctors who participated in the  
332 study, the questionnaire was most often filled out by the patient, but we do not know the exact  
333 number of questionnaires that were filled out by witnesses. This could have affected the speed  
334 estimate or the type of accident that was reported. The victims' perception of their own  
335 behavior could differ from that of a witness. However, this difference would not have had any  
336 effect on the responses to questions that were not open to interpretation, such as information  
337 about the patient (sex, age), the type of TWMV used, the protective gear used, and the place  
338 where the accident occurred. The second part, which was filled out by the doctor and provided  
339 information about the medical evaluation, was not subject to this type of problem. This  
340 enabled us to obtain a robust estimate of the mechanisms of injuries that occurred during the  
341 accidents.

## 342 5.2 The use of back protection

343 No figures regarding the rate of wearing back protection have been published for France. In  
344 this study, 43% of victims of TWMV accidents who were seriously injured were wearing  
345 back protection. This is a relatively high rate, but is very similar to the rate of back protector  
346 use among TWMV riders reported in a study from New South Wales in Australia that was  
347 published in 2006 (44%).

348 In this study, participants were specifically asked "were you wearing a back protector at the  
349 time of the accident?" at the beginning of the interview, but no distinction was made between  
350 the different types of back protectors: those that are integrated into riding jackets or separate  
351 back protectors, and level 1 or 2 according to the norm. Integrated and separate back  
352 protectors are intended to protect the thoracic and lumbar vertebrae. However, separate back  
353 protectors can be adjusted to fit better than integrated back protectors and are sometimes large  
354 enough to cover the shoulder blades. When the data were collected, a specific description of

355 the type of back protector used could have been requested. However, given the sample size, it  
356 was difficult to explore this level of detail.

### 357 5.3 Characteristics of injured individuals

358 The results from the univariate analyses show that the severely injured patients had a  
359 tendency to be injured following a collision with a vehicle (48%) or following a solitary fall  
360 (23%) on an avenue, boulevard, or city road (43%). These victims were, for the most part,  
361 experienced young men. Nevertheless, there was a difference in the level of protection used,  
362 the cylinder size, and the estimated speed at the time of the accident. Two characteristic rider  
363 profiles emerged from the analysis.

364 The first profile was primarily composed of riders of large cylinder vehicles ( $> 125 \text{ m}^3$ ) who  
365 were attentive to their protective equipment (back protector, full-face helmet, elbow pads,  
366 jacket, certified pants, gloves) and riding at a speed that they considered to be moderate at the  
367 time of the accident. The second profile was composed of riders of small cylinder vehicles ( $<$   
368  $125 \text{ m}^3$ ) who were much less attentive to their protective equipment. They were not wearing  
369 back protection or neck protection. Only rarely were these riders wearing a jacket, gloves,  
370 elbow pads, or certified pants. In addition, they estimated their speed as fast at the time of the  
371 accident (Table 1). The identification of these two profiles will allow preventive campaigns  
372 to better target to this population to encourage them to use protective equipment or even  
373 advise them regarding the limitations of this type of equipment when it comes to protection  
374 from injury.

### 375 5.4 Thoracolumbar lesions:

376 According to the data, the riders who were not wearing back protectors were involved in  
377 accident scenarios that were potentially more serious than those faced by riders who were  
378 wearing back protectors. High speeds, which are known increase traumatic injuries, and very

379 limited use of protective gear at the time of the accident confirm this greater exposure to the  
380 risk of more severe injuries. Nevertheless, the severity was not confirmed by the nature and  
381 number of thoracolumbar injuries observed in this study (only three AIS+3 injuries were  
382 observed in victims who were not wearing back protectors). Despite these relatively opposite  
383 rider profiles, the study did not show any difference significant in injuries between these two  
384 groups (table 2). Even if the number of burst injury is slightly higher for individuals without  
385 back protection than individuals with back protection, fisher's test did not highlight it. Thus,  
386 we can say that the two profiles overall had the same number and type of injuries. The injury  
387 mechanisms did not differ depending on the use of back protection. The axial compression  
388 characteristic of type A lesions according to the Magerl classification system is the most  
389 common mechanism of thoracolumbar injuries. It occurs due to an impact in the craniocaudal  
390 direction. Multiple injury mechanisms with potentially multidirectional force loads can occur  
391 during TWMV accidents. Back protectors, which are designed to protect users from impacts  
392 in a posterior-anterior direction, do not protect riders from the axial forces that cause  
393 compression injuries. Among the injury data collected from the riders who were not wearing  
394 back protectors, very few injuries linked to posterior-anterior impacts could have been  
395 avoided by the use of back protection. Thus, it is difficult to draw any conclusions regarding  
396 the effectiveness of back protection given that this type of protector is designed to prevent  
397 posterior injuries, which did not appear in the study population.

398

399 Other studies suggest that the majority of spinal injuries that occur during TWMV accidents  
400 are caused by flexion and torsion forces, and not by direct impacts on the vertebral column  
401 (de Rome, 2006). Thus, this study highlights the necessity of preventing compression injuries,  
402 which, instead of being prevented by wearing a back protector, are deflected to the thoracic  
403 spine (lumbar vertebra-medullary lesions are deflected to the thoracic vertebrae), and the

404 medical implications of these injuries are known to be potentially much more significant. This  
405 finding clearly defines the challenge of developing new back protectors that prevent these  
406 injuries instead of deflecting them to the adjacent spinal segment.

407 Studies have identified the thoracic region as the region that is most commonly affected in  
408 TWMV users who are involved in accidents (Ankarath et al., 2002). Our results show that,  
409 among victims of serious TWMV accidents, 27% had thoracic injuries and 17% had lumbar  
410 injuries. The greater number of injuries at the level of the thoracic vertebrae reveals that the  
411 thoracic spine is overexposed. In addition, this is the area of the spine that is most curved, and  
412 is thus likely to be more sensitive to structural buckling. The smaller size of the thoracic  
413 vertebrae could also explain why their fragility is increased by the presence of the back  
414 protector, which, by restraining spinal mobility, increases the risk of a local break. Here again,  
415 a detailed biomechanical analysis based on digital simulation could confirm the hypotheses  
416 generated in this study.

## 417 6. Conclusion

418 This multidisciplinary study, which combined epidemiological data with a clinical and  
419 biomechanical analysis, allowed us to identify the mechanisms of thoracolumbar injuries  
420 sustained during TWMV accidents as a function of wearing back protection.

421 The results from this study show that the use of back protectors is widespread, as 43% of  
422 individuals who sustained serious injuries were wearing a back protector at the time of the  
423 accident. This study does not aim to question the effectiveness of back protectors in protecting  
424 users from impacts in a posterior-anterior direction. Currently available back protectors are  
425 not appropriate for protecting against impacts in a craniocaudal direction. It is therefore  
426 important to clarify messages regarding the effectiveness of this type of gear and determine  
427 how to develop back protectors that better protect the spine.

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