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# Pedestrian injuries in eight European countries: An analysis of hospital discharge data

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ABSTRACT

Out of the 50,000 yearly road traffic deaths in the European Union (formed by 27 European countries and commonly designated as EU-27), some 8500 are pedestrians. While some studies focus on the increased risk for pedestrian mortality compared to other road users, there is a dearth of information on injury patterns that could be used to prioritize injury prevention measures. Hospital discharge data from eight European countries have been used in this study. Injury information from 10,341 pedestrians sustaining 19,424 injuries has been analyzed. Data have been augmented with Abbreviated Injury Scale, Functional Capacity Index and Injury Severity Score codes, and have been categorized into the Barell Matrix. Fractures (51.1%, 50.3–51.8) and internal injuries (21.3%, 20.7–21.9) are the most frequently found in the data; however, blood vessel injuries and internal injuries are the ones associated with the highest risk of death. Head and lower extremities account for 26% of the injuries each, being spinal and thoracic injuries those showing the highest threat to life risk. Hip and lower extremities injuries are the most frequent cause of functional limitation 1 year after discharge. Due to its intrinsic importance, different injury causation mechanisms for head injuries have been analyzed. Though current standards and regulations consider Head Injury Criterion (HIC) as the only tool to assess the risk of injuries to the head, real world injury data show that only 12.1% (11.0–13.2) of these injuries can be attributed to a pure translational mechanism and therefore susceptible to be predicted by HIC. Design of prevention strategies, particularly from the engineering point of view, should benefit from this information.



## 1. Introduction

The World Health Organization estimates that 1.2 million people lose their lives in road traffic crashes every year (WHO, 2004). It has been reported that the percent of these deaths that are pedestrians ranges from a low 5% (for example in the Dominican Republic) or 10% (in Brunei, Thailand or Netherlands), to 42% in Delhi (India), or a high 78% in Peru (Odero et al., 1997; Pucher et al., 2007; WHO, 2009). In Europe, 48% of road traffic deaths among children ages 0–14 are pedestrians, whereas it lowers to 21% as they age to the 15–17 years old group (Sethi et al., 2008).

Even though more pedestrian deaths occur in less developed countries, they are not uncommon in developed environments. For example, every year, 5000 people die and some 60,000 are injured as pedestrians in the United States (Chakravarthy et al., 2007). Out of the almost 50,000 yearly road traffic deaths in the European Union (EU-27), some 8500 are pedestrians (Angerman et al., 2007). Pedestrian injuries are the leading cause of death among Scottish children under 15 years old (Pearson and Stone, 2009). In addition, pedestrian injuries represent a leading cause of hospitalization and death as road traffic victims among the elderly (Kim et al., 2008).

Most of the published studies on pedestrians focus on mortality-related issues, demonstrating for example their higher likelihood of death when compared to other road users (Kim et al., 2008) or other personal and crash risk factors, such as age (Chini et al., 2009; Kim et al., 2008; Pearson and Stone, 2009). Police-related databases are commonly used for these evaluations, with Sze and Wong (2007) being the paper of this kind with the largest sample size. In contrast, papers covering the non-fatal but serious outcomes are less common. In fact, we could only identify a few and they focus either on very particular geographical areas (a city in many instances) (Chini et al., 2009; Otte and Huefner, 2007) or on a limited number of cases (Otte and Huefner, 2007; Yao et al., 2006; Neal-Sturgess et al., 2007).

Motor vehicle occupant mortality has been reduced substantially over the last decades, especially in developed countries. Some

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of this reduction can be explained by the shift in transportation mode from walking into motorized vehicle occupants (DiGuiseppi et al., 1998), which in turn has been linked to the increasing epidemic of obesity (Dwyer et al., 2007). Another important factor explaining the overall motor vehicle mortality reduction is the development and implementation of passive safety measures to protect vehicle occupants (Farmer and Lund, 2006). Thus, it is sensible that with the current efforts to promote walking as a primary source of physical exercise in our population (Physical Activity Guidelines Advisory Committee, 2008), we also promote the development of passive safety measures to reduce the potential burden of injuries to pedestrians. Yet, in order to do so, specific injuries need to be identified for which to develop countermeasures.

An example of the interest in developing pedestrian-specific measures is the 2005 implementation of a European directive (2003/102/CE) by which all new types of vehicles have to fulfill pedestrian protection requirements, consisting of experimental tests with head impactors ensuring biomechanical values during a collision under some limits (EC, 2003). The effectiveness of this regulation is not evaluated yet. Another example is the pedestrian-related EuroNCAP test conducted since 1996 and recently incorporated to the overall car safety rating (EuroNCAP, 2009). Both in the European directive and in the EuroNCAP tests, the Head Injury Criterion (HIC) is the metric being used to prevent head injuries. The shortcomings of this injury criterion to detect injuries to the head caused by a rotational acceleration have already been pointed out in the literature (Martin and Eppinger, 2002; Mackay and Petrucelli, 1989).

Whether one is to develop pedestrian-specific measures addressing the most frequent injuries, the most lethal ones (i.e., severity), the most disabling ones, or combinations of the above, is a political decision. But not all databases can assist in this decision making process. Police reports, even if non-fatal injury data are collected, lack detail on the location or nature of the sustained injuries (Chini et al., 2009) and, further, they underestimate the number of pedestrian fatal victims (Sciortino et al., 2005). In-depth databases, such as the USA National Automotive Sampling System Crashworthiness Data System (NASS CDS) or the German In-Depth Accident Study (GIDAS) provide crash and injury details, but they rarely focus on pedestrians. This means that even though pedestrians can be found in their datasets, they lack population representativity. There are no large electronic databases with pedestrian-related autopsy data that could be investigated to determine the frequency of injuries among fatal cases. Interestingly, health sector databases, such as emergency room and hospital discharge data, contain medical information on the sustained injuries and allow for broad characterization by road user type (Chini et al., 2009; Loo and Tsui, 2009).

The goal of our study was to evaluate the distribution of hospitalized pedestrian injuries in Europe by frequency, severity and resulting disabilities so as to serve as a benchmark against which to evaluate intervention measures currently under implementation. In addition, we paid special attention to head injuries and to their associated causal injury mechanism to assess the adequacy of the injury metric included in current safety regulations and standards.

## 2. Data and methods

Country- and age-specific population data were extracted from Eurostat (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/). Relevant rates of hospitalized pedestrians per 100,000 population were computed using the direct standardization method. Pedestrians were categorized by age as <12, 12–56 (if women) or 74 (if men), and ≥57 (if women) or 75 (if men). Rationale for this gender-dependant age classification was to account for differences in bone density and fracture risks with age and gender (De Laet and Pols, 2000).

Hospital discharge data from eight European countries (i.e., Bulgaria (BU), Hungary (HU), Netherlands (NT), Norway (NO), Portugal (PT), Slovenia (SL), Spain (SP), and Sweden (SW)) were gathered as part of an EU-funded project (APOLLO EU DG SANCO 2004119). These eight countries amounted to 100.4 million Europeans in 2004, the year for which data were collected. Hospital discharge records were included if they had at least one injury code. In these countries, injuries are coded according to one of the two latest versions of the International Classification of Diseases (ICD), ICD-9-CM and ICD-10. Specific codes indicating injuries were ICD-9-CM 800.0-995.85 and ICD-10 S00.0-T98.3, respectively. Pedestrians were included in this study if they had received either of these codes in any of the first three diagnosis fields (Segui-Gomez et al., 2008). Discharges classified as readmissions were excluded from further analysis (i.e., only primary admissions were considered in the analyses). In the discharge data, pedestrians are defined as having either E-Codes 805.2, 806.2, 810–825 (.7), or 826–829 (.0) in the ICD-9-CM classification or V01 to V09 in the ICD-10 classification.

Participating countries submitted their data on age, gender, type of admission, discharge disposition (dead, home, transfer to another hospital), up to three diagnoses, the external cause of injury code (E codes in ICD-9-CM or VXYZ codes in ICD-10), and duration of hospital stay. Data on injury diagnoses were further categorized into the Barell Matrix in order to present frequency counts (Barell et al., 2002; European Center for Injury Prevention at Universidad de Navarra, 2007b; European Center for Injury Prevention at Universidad de Navarra, 2007a; Fingerhut and Warner, 2006). The Barell Matrix consists of a two-dimensional array categorizing ICD codes pertaining to body region and nature of injury simultaneously. This Matrix provides a standard format that can be used in trauma registries, hospital discharge data systems, emergency departments, etc. to report on injury data (Barell et al., 2002).

We then augmented these data using algorithms to derive Abbreviated Injury Scale (AIS) scores (1998 version-AIS98) (AAAM, 1998), Injury Severity Scores (ISS), (Baker et al., 1974; Segui-Gomez and Ewert, 2008; Segui-Gomez and Ewert, 2008; Center for Injury Research and Policy of the Johns Hopkins University School of Public Health and Trianalytics, Inc, 1998; European Center for Injury Prevention at Universidad de Navarra, 2007d), as well as the Functional Capacity Index (FCI) (European Center for Injury Prevention at Universidad de Navarra, 2007c).

The AIS is the most widely used scale in the motor vehicle safety and injury prevention literature to assess severity, defined as a threat to life. The AIS severity score is an ordinal scale ranging from 1 to 6 that uses consensus-derived information on the severity of individual anatomical injuries. Although the scale has been revised several times, the 1998 update of the 1990 version was used for this paper (AAAM, 1998). To integrate the severity of subjects sustaining several injuries, the ISS was developed and it combines the three most severe injuries in three separate body regions to create an ordinal scale ranging from 1 to 75 (Baker et al., 1974).

The FCI is a preference-based outcome measure developed for non-fatally injured adult patients that defines health across 10 dimensions (eating, excretory, sexual, ambulatory, hand, bending and lifting, visual, auditory, speech and cognition) and varying levels of functioning within each dimension. Although the measure can be applied in several formats, one such application involves a consensus-based process of a group of experts who assigned predicted functional limitations to every AIS98 code. This is known as the pFCI-AIS98 (AIS 2008). These predictions can be transformed into a single numeric code ranging from 100 (worst possible state) to 0 (no limitation, perfect health state). Previous applications of the scale suggest that a 7% of motor vehicle victims sustain some remaining functional limitation 1 year after the crash (i.e., FCI < 100)

**Table 1**
2004 injury-related hospital discharge data by country ($N$ = 100.4 million inhabitants).

| | Injury hospitalization counts (all external causes, excluding readmissions) | % of discharges with external cause of injury information | Discharges identified as pedestrians | Age and gender-adjusted pedestrian hospitalization rates (per 100,000 pop) | Pedestrians dead during hospitalization |
|---|---|---|---|---|---|
| Bulgaria | 47,331 | 14.5 | 273 | – | 17 |
| Hungary | 150,250 | 90.0 | 2249 | 18.6 | 58 |
| Netherlands | 135,475 | 100.0 | 1248 | 5.8 | 32 |
| Norway | 114,799 | 16.9 | 352 | – | 10 |
| Portugal | 85,905 | 99.7 | 1919 | 12.4 | 103 |
| Slovenia | 32,384 | 88.0 | 541 | 22.8 | 11 |
| Spain | 340,192 | 45.5 | 2763 | – | 186 |
| Sweden | 179,375 | 79.0 | 996 | – | 26 |

–: Not calculated because % of external cause of injury information was available in less than 80% of cases.

(Segui-Gomez, 1996), with varying amounts of limitations by user type (Segui-Gomez and Ewert, 2008).

Because of the reported relevance of traumatic brain injuries in pedestrians (in terms of frequency, mortality rates, and residual limitation), diagnoses related to traumatic brain injury (ICD-9-CM codes: 800–804 (with selected 4th and 5th digits) and ICD-10 codes: S02, S2, and T90 (with selected post dot digits)) were further classified according to an algorithm developed by Martin (Martin and Eppinger, 2002; European Center for Injury Prevention at Universidad de Navarra, 2008) to identify whether the injuries related to translational accelerations, rotational accelerations or either. Gennarelli (1993) describes two general types of brain injuries: focal injuries and diffuse injuries. Focal injuries are caused mainly by direct impacts to the head and they encompass contusions, lacerations and hemorrhages that produce hematomas in the extradural, subdural or intracerebral compartments of the head. Diffuse injuries are often caused by inertial mechanisms in which there is relative motion of the cranial contents. If the inertial acceleration is translational, the most common injuries are vasculature injuries such as countercoup contusions and subdural hematomas. However, if the inertial motion is caused by a rotational acceleration, the injuries associated are caused by strains that cause Diffuse Axonal Injuries (DAI) associated to cerebral concussions, post-traumatic coma and unconsciousness. Therefore, it is possible to associate a specific brain injury to a specific type of acceleration. This is of particular importance, since the metric (HIC) used in the above mentioned standards is capable, by definition, of capturing only those injuries associated to translational acceleration mechanisms. Thus, non-translational head injuries would not be addressed by the standards and, therefore, not prevented.

Analyses report on pedestrians sustaining injuries and being admitted to hospital. When needed, the analyses focused on injuries rather than on pedestrians. The basic unit of analysis is indicated in each case. If patients presented more than one injury, death was attributed equally to all sustained injuries, whereas AIS and pFCI-AIS98 are presented according to the worst such injury sustained by the individual. Descriptive analysis with point estimates and 95% confidence interval (CI) estimates were done using Stata v.9.0 (Stata Corporation, 2005).

## 3. Results

Across the eight countries, 1,085,711 discharge records were of primary admissions with at least one injury diagnosis in the first three diagnoses. The percent of discharges with information on the circumstances leading to the injuries (i.e., the external causes) ranged from 17% (Norway) to 100 (Netherlands), being 80% or higher in another three countries (Portugal, Hungary and Slovenia). Out of the hospitalizations with external cause information, 10,341 were identified as pedestrians and 443 (4.3%) of them died during the hospital stay. Table 1 provides the counts per country as well as the age-adjusted hospitalization rates for four countries with complete external coding. Hospitalized pedestrian rates range from 5.8 per 100,000 population in the Netherlands to 22.8 in Slovenia.

The ages of the hospitalized pedestrians ranged from less than 1 to 99 (mean 43.8, SD 26.4), and 56% of them were boys or men. The age and gender distribution of these pedestrians is provided in Fig. 1 with a breakdown by fatal outcome. Among the less than 12-year-old subjects, it is more likely to be hospitalized as a pedestrian being a boy than being a girl, whereas the opposite is true in older ages.

The 10,341 discharge records provided data on 19,424 injuries, with an average of 1.9 injuries per case (SD 0.84). The distribution of those injuries by body region affected and type of injury is presented in Table 2. Fractures and internal injuries are the type of injuries more frequently found in the data, accounting for the 51.1% (50.3–51.8) and 21.3% (20.7–21.9) of the total number of injuries, respectively, followed by contusion and superficial injuries (10.2, 9.8–10.7). As for the body region injured, head and lower extremity amount to 26% each (26.6, 25.9–27.2 and 26.2, 25.6–26.9 respectively), followed by upper extremity injuries (11.1, 10.7–11.6). As for the combination of body region with the type of injury, fractures to the lower extremities (21.6, 21.0–22.2) are the most common reported injuries followed by internal traumatic brain injuries (17.5, 16.9–18.0) with 6.3% (5.9–6.8) of the patients simultaneously presenting injuries in both body regions.

Fig. 2 illustrates the percent of those injuries leading to death during hospitalization, classified independently according to body region and type of injury. The $X$-axis is located at 4.3%, the overall percentage of death among these hospitalized pedestrians as

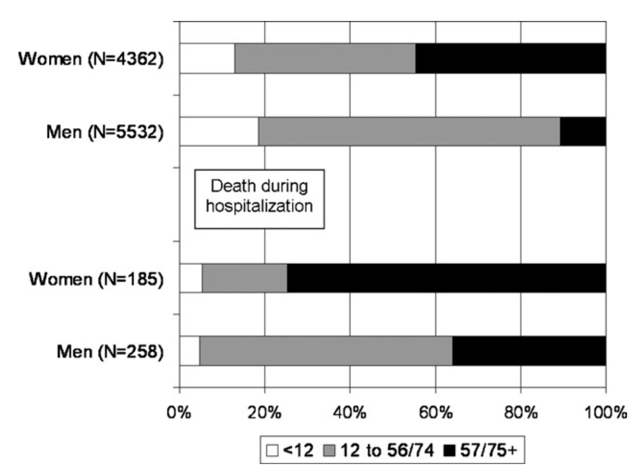


**Fig. 1.** Age and gender distribution of hospitalized pedestrians by survival upon discharge ($N$ = 10,337 patients; unknown sex = 4). Upper rows: pedestrians discharged alive from hospital. Lower rows: pedestrians that died during hospitalization.

**Table 2**
Joint Barell Matrix (ICD-9-CM and ICD-10 for 10,341 hospitalized pedestrians in eight European countries (BU, HU, NT, NO, PT, SL, SP, SW), 2004. Percent distribution (and 95% CIs*) ($N = 19{,}424$ injuries).

| | Fracture | Dislocation | Internal | Open wound | Amputations | Blood Vessels | Contusion/ superficial | Crush | Burns | Others | Unspecified | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Traumatic brain injury | 4.6 (4.3–4.9) | 0 | 17.5 (16.9–18) | 1.7 (1.5–1.8) | 0 | 0 | 0 | 2 (1.8–2.2) | 0 | 0.9 (0.8–1) | 0.02 | 26.6 (25.9–27.2) |
| Other head | 2.7 (2.5–2.9) | 0.02 | 0 | 2.5 (2.2–2.7) | 0 | 0 | 1.2 (1–1.3) | 0 | 0.04 | 0.04 | 0.2 (0.2–0.3) | 6.6 (6.3–7) |
| Neck | 0.02 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0 | 0 | 0.06 | 0.01 | 0.1 |
| Neck and head other | 0 | 0 | 0 | 0 | 0 | 0 | 1.4 (1.3–1.6) | 0 | 0.01 | 0 | 0.1 (0.09–0.2) | 1.6 (1.4–1.8) |
| Spinal cord | 0.2 (0.1–0.3) | 0 | 0.2 (0.18–0.3) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 (0.3–0.5) |
| Vertebral column | 2.4 (2.2–2.7) | 0.1 (0.07–0.2) | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 (0.5–0.7) | 0 | 3.1 (3–3.4) |
| Thorax | 3.4 (3.2–3.7) | 0 | 2.1 (1.9–2.4) | 0.03 | 0 | 0.04 | 1.3 (1.1–1.4) | 0.01 | 0 | 0.4 (0.3–0.5) | 0 | 7.3 (7–7.7) |
| Abdomen, pelvis, trunk and lower back | 4.6 (4.3–4.9) | 0.01 | 1.4 (1.3–1.6) | 0.2 (0.1–0.3) | 0 | 0.06 | 1.7 (1.6–1.9) | 0.09 | 0 | 0.04 | 0.04 | 8.2 (7.8–8.6) |
| Upper extremity | 8.2 (7.7–8.6) | 0.6 (0.5–0.7) | 0 | 0.8 (0.7–0.9) | 0.07 | 0.04 | 1 (0.9–1.1) | 0.05 | 0.02 | 0.3 (0.2–0.3) | 0.03 | 11.1 (10.7–11.6) |
| Lower extremity | 21.6 (21–22.2) | 0.2 (0.1–0.3) | 0 | 1 (0.9–1.2) | 0.5 (0.4–0.6) | 0.04 | 1.6 (1.4–1.8) | 0.3 (0.2–0.4) | 0.02 | 0.9 (0.7–1) | 0.1 (0.09–0.2) | 26.2 (25.6–26.9) |
| Hip | 2.7 (2.5–2.9) | 0.1 (0.07–0.2) | 0 | 0.02 | 0 | 0 | 0.4 (0.3–0.5) | 0.04 | 0 | 0.07 | 0 | 3.4 (3.1–3.7) |
| Multiple body regions, system wide and unspecified | 0.5 (0.4–0.6) | 0 | 0 | 1 (0.9–1.2) | 0.03 | 0.03 | 1.7 (1.5–1.9) | 0.06 | 0.04 | 0.3 (0.2–0.4) | 1.5 (1.3–1.7) | 5.2 (4.9–5.5) |
| Total | 51.1 (50.3–51.8) | 1.1 (1–1.3) | 21.3 (20.7–21.9) | 7.2 (6.9–7.6) | 0.6 (0.5–0.7) | 0.2 (0.1–0.3) | 10.2 (9.8–10.7) | 2.5 (2.3–2.8) | 0.1 (0.08–0.2) | 3.5 (3.2–3.8) | 2 (1.9–2.3) | 100 |

* Confidence intervals not calculated when $n < 2$.

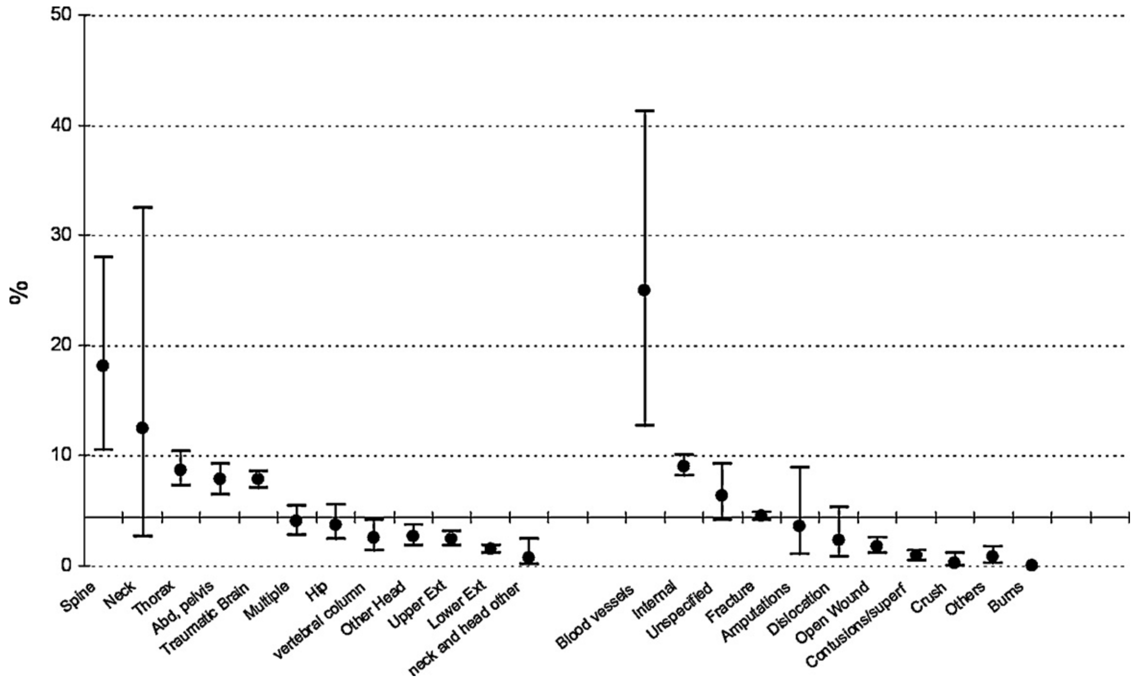


**Fig. 2.** Percent (and 95% CI) of hospitalized pedestrians dead during hospital stay by body regions and types of injuries ($N$ = 10,341, average $p$ (death) = 4.3%), eight European countries (BU, HU, NT, NO, PT, SL, SP, SW), 2004.

described above. Even though a very frequent injured body region such as the brain has a higher probability of death than the average, other body regions sustain higher percentages of death, including spine, thorax and abdomen-pelvis. As for the type of injury, blood vessel injuries present a 25% of death during the hospitalization episode (12.7–41.2) followed by internal injuries.

Most of the hospitalized subjects sustained a maximum AIS score (MAIS) of 2 (51.5%, 50.7–52.7), with 21.7% (20.9–22.5) sustaining a MAIS of 3, 12.4% (11.7–13.0) a MAIS of 1, 4.6% (4.2–5.1) a MAIS of 5, 4% (3.7–4.4) a MAIS of 5, 2% (1.7–2.2) a MAIS of 6, and the remaining subjects having unspecific codes leading to no AIS scores. The distribution of ISS scores highlights that 63.1% (62.2–64.1) of hospitalized patients have ISS scores in the 1–8 range, with 21.4% (20.6–22.2) ranging from 9 to 15, 5.4% (5.0–5.9) ranging from 16 to 24, and 6.4% (5.9–6.9) in the 25–75 range. Only around 2.9% of the cases had unspecific ISS values.

Regarding the predicted functional limitations analysis of those 18 years old or older who were discharged alive, 14.7% (13.9–15.5)

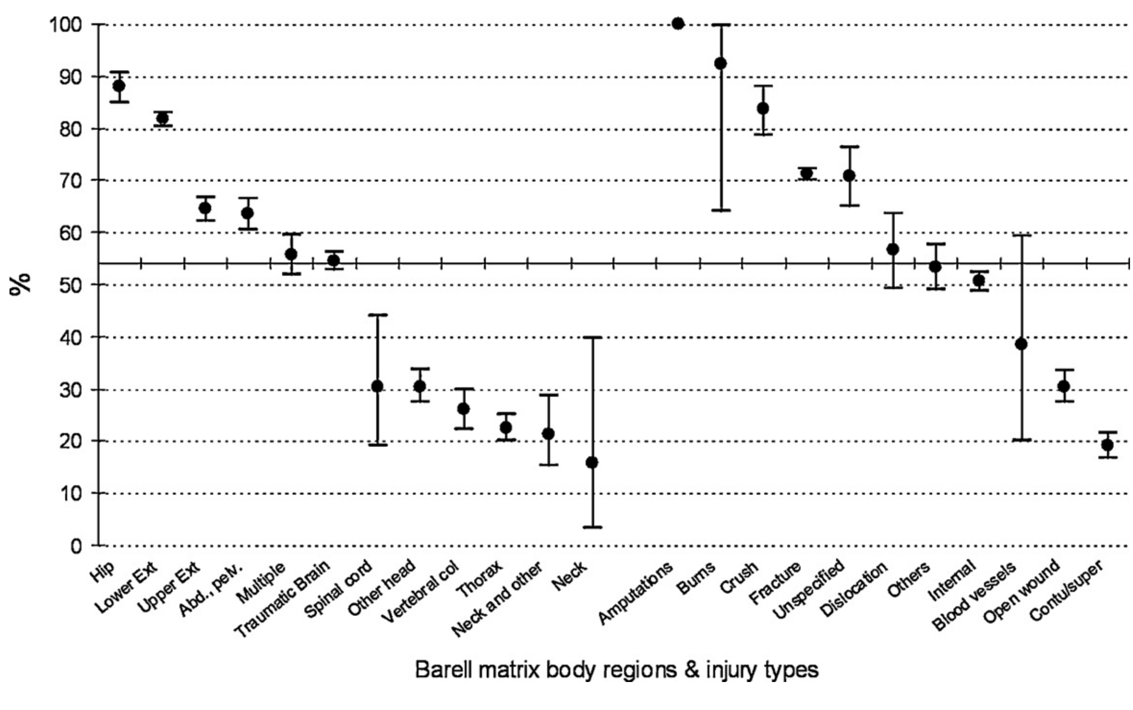


**Fig. 3.** Percentage (and 95% CI) of hospitalized adult pedestrians discharged alive who are expected to have some functional limitation one-year post-discharge, according to the Predicted Functional Capacity Index based on AIS98 scores by body region and type of injury. Eight European countries (BU, HU, NT, NO, PT, SL, SP, SW), 2004 ($N$ = 6354 subjects 18 years old or older, average p(pFCI-AIS) < 100 = 54).

of the patients had AIS codes that could not be matched to pFCI-AIS due to their lack of specificity. However, among those whose information was specific enough, 46% (44.8–47.2) were expected to be fully functional and well 1 year after the injury, with the remaining subjects sustaining varying degrees of functional limitations. Fig. 3 presents the specific percentage of individuals predicted to sustain any limitations by body region injured and type of injury sustained (i.e., the injury leading to the worst expected functional limitation for that individual), and again the *X*-axis is placed at the average value of 54%. Among body regions, hip injuries and injuries to the lower extremity lead the ranking, presenting the largest percentages of individuals with some residual disability 1 year after the crash, at around 80–90% of the victims. This is followed by injuries to the upper extremity, abdomen, pelvis, trunk and lower back, multiple injuries and traumatic injuries with some 60–70% of victims suffering residual limitations. All other injury types lead to these limitations in 30% of less of the cases. As for the types of injuries, there seems to be a continuous transition from injuries leading to limitations in 100% of the cases, such as amputations, to injuries leading to limitation in around 20% of the cases, such as contusion or superficial injuries.

Out of the 3403 pedestrians with head injuries for which their injury information was specific enough to allow for classification of the mechanisms leading to those injuries, 56.5% (54.8–58.2) presented injuries related exclusively to rotational mechanisms, 12.1% (11.0–13.2) presented injuries associated with translational ones, 5.0% (4.3–5.8) had injuries that could be explained by either, and the remaining 26.4% (24.9–28.0) of patients' injuries were the result of both mechanisms combined.

There was not enough information to determine the type of vehicle impacting the pedestrian in 53.1% of the cases. Yet, among the 46.9% of the cases in which this information existed, a 4-wheel vehicle was the most common contact source (29.1% (28.3–30.0)) followed by "other" 11.7% (11.1–12.4), bicycles (4.9% (4.5–5.3), and 2-wheel vehicles (1.1%, 0.9–1.3).

## 4. Discussion

Our findings highlight the injury patterns of pedestrians in eight European countries using the largest gathering of pedestrian injury information ever.

Even though a comprehensive analysis of injury patterns should include those who die at the scene (and therefore, are not admitted to hospital), it is noteworthy to indicate that in the four countries in which mortality data in 2004 are available, pedestrian deaths during hospitalization represented from 27% (Spain) to 48% (Netherlands) of all police-reported pedestrian deaths occurring in these countries. Unfortunately, we have not been able to identify any publication describing injury patterns for dead pedestrians at a population level, most likely a consequence of the difficulties in accessing population-based injury mortality data that will describe the nature of the injuries.

Thus, though pedestrians who died at the scene are not included in our data, we have retrieved injury information from all the pedestrians that were admitted to hospital ($N = 10,341$). Even if partial, hospitalization data on pedestrians is particularly relevant since pedestrians are one of the user types with highest risk of hospitalization (Chini et al., 2009), particularly among children (Edwards et al., 2008) and the elderly (Loo and Tsui, 2009). Previous pedestrian-related studies included, at most, 1000 pedestrian cases each (Otte and Huefner, 2007; Yao et al., 2006) and the population representativity of these is questionable (Yang and Otte, 2007).

The above-mentioned studies used in-depth road traffic crashes databases to analyze pedestrian injury patterns. It is a common finding that injuries to the head and to the lower extremities are the most frequent injuries found in pedestrians. Both are important: the first one can constitute a serious threat to life, while the second one can cause significant and permanent disabilities. Otte and Huefner (2007) analyzed the pattern of injuries sustained by pedestrians in different crash situations using data from the German in-depth database GIDAS. Regardless of the crash situation, this study reports between 62.4% and 51.5% of injuries to the head while we have observed around 33% of injuries to the head. These differences can be explained by the limited sample size of the in-depth study ($n = 1107$). Yang and Otte (2007) compared data from GIDAS with data collected in a local hospital in Changsha (China). Interestingly, data from Germany shows again that 50.7% of injuries were to the head, while Chinese data report only a 31.5%. It is not clear from the discussion of this paper why they found such big differences.

When bigger sample sizes are considered, figures are closer to the results presented in this paper. Sze and Wong (2007) reported an increase in the risk of death or hospitalization when injuries to the head are present, using police data. We have found a comparable finding for the risk of death. They also reported similar findings on gender and age distribution. Loo and Tsui (2009) found a higher mortality risk for pedestrians being 65 years or older (3.61 times (1.16–11.25)) than in younger pedestrians. This is also reflected in our data.

Also for the first time we have been able to conduct an extensive analysis of the mechanisms responsible for head injuries. Though, again, we did not have the needed information to perform this analysis on all the cases (due to the lack of information in the description of some injuries), our sample size in this analysis was 3403 pedestrians with head injuries. Our results show that more than half of the injuries to the brain are associated exclusively to a rotational acceleration that is not considered in the formulation of HIC (Melvin and Lighthall, 2002). A reduction on HIC will bring improvement to the reduction of head injuries, but only to those caused by a translational acceleration mechanism. However, in light of these data, it might be worthy to consider the implementation of additional head injury criteria assessing the other mechanisms of injury.

Our set of data does not embrace the whole population of pedestrian victims. We are missing fatalities on-the-spot and pedestrians that have been admitted to hospital but were never recorded as pedestrians in the hospital discharge data. The need of the linkage of different trauma and crash databases have been pointed out repeatedly in the literature (Loo and Tsui, 2009; Cryer et al., 2001; Rosman, 1996). Also, we do not claim that our participating countries are representative from Europe at large. However, this is the first time that population-based data from four countries and additional cases from four other countries are analyzed together describing the nature and severity of injuries. Moreover, it is the first time that data from more than one country are analyzed and the study with the largest number of pedestrians with injury information beyond survival to the impact.

Hospital discharge data have also limitations. Since pedestrian status was determined through the external codes, we missed the opportunity to have population-based data from Bulgaria, Norway, Spain and Sweden. In Norway and Sweden, this relates to the coding system used to characterize user type—an issue that could be solved with increasing standardization of codes. In the case of Bulgaria and Spain, the incompleteness of the data reflects a solvable problem long reported (Langlois et al., 1995). We found no studies documenting whether underreporting is biased with regards to the type of users, and we chose to act conservatively not inferring from missing data. Last, on these codes, it is interesting to note the high level of unspecificity that prevented us from identifying the hitting object in almost half of the cases identified as pedestrians, an issue also reported in the literature (Lawrence et al., 2007). Nevertheless, we believe that our study offers the most comprehensive description of pedestrian injuries to date.

We believe that the data presented here can be used as a valuable resource to prioritize injury prevention strategies as well as a benchmark to evaluate the effectiveness of these strategies. As regards to prioritizing interventions, even though lower extremity and traumatic brain injuries represent the most common injuries, we should not forget the relevance of others. For example, with regards to death, spinal, neck, thoracic, and abdominal and pelvic injuries share with traumatic brain injuries an increase in the probability of death, whereas injuries to blood vessels and internal injuries are more fatal than fractures or other injuries. Regarding injuries with long-lasting sequelae, only abdominal and pelvic injuries share with traumatic brain injuries a significant likelihood of both increasing probability of death and functional limitations. In contrast, not particularly life threatening injuries, such as injuries to the hip, lower and upper extremities, are expected to have more limiting effects on survival. These findings, as well as the one highlighting the high percentage of head injuries caused by rotational acceleration, should be born in mind at the time of designing new regulations and standards concerning pedestrian protection. For instance, despite the importance of thoracic or abdominal injuries, there is no current pedestrian protective countermeasure designed to prevent injuries to these regions. Decision makers and automotive industry can find these results relevant to assist them in the design of new policies and countermeasures.

## 5. Conclusions

We cannot prevent what we do not know. Previous attempts to characterize the frequency, distribution and severity of injuries to pedestrians have never reached the volume of data herein presented. Furthermore, we also present an estimation of long-lasting disabilities resulting from these injuries. Design of prevention strategies, particularly from the engineering point of view, should benefit from this information. It is somewhat paradoxical, for example, that the only legislation in place to project pedestrians in the EU uses a unique head injury predictor, the Head Injury Criterion, which takes into account only translational acceleration. It is very important to address the issue of vehicle design in this regard. However, our study points out that linear acceleration is only partially responsible of these very frequent, severe and disabling injuries.

## Conflict of interest

The authors report no conflict of interest.

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