Motorcyclist Impacts into Roadside Barriers

Is the European Crash Test Standard Comprehensive Enough?

Raphael Grzebieta, Mike Bambach, and Andrew McIntosh

This paper reports on a study that reviewed the European Standard EN 1317-8 for motorists crashing into barriers and the relevance to Australian motorcycle fatalities. The data collection and analysis of 78 Australian motorcyclist-into-barrier fatalities described here were used to justify the review. In Australia each year approximately 15 motorcyclists die from striking a road safety barrier. A retrospective analysis of the fatalities during 2001 to 2006 ($n = 78$) was carried out. Consistent with European findings, approximately half the motorcyclists were in the upright posture when they struck the barrier, whereas half slid into the barrier. The mean precrash speed was 100.8 km/h, and the mean impact angle was 15.4°. The areas of the body that were injured were similar across different barrier types (concrete, wire rope, and W-beam) and crash postures. The thorax area had the highest incidence of injury and maximum injury in fatal motorcycle crashes into barriers; the head area had the second-highest incidence of injury. Moreover, thorax and pelvis injuries had a greater association with sliding crashes than with those in the upright posture. The existing European Standard EN 1317-8 addresses only the sliding mechanism, uses a head injury criterion, and does not specify any thorax injury criterion. It was proposed that a thorax injury criterion and an additional test should be introduced with the rider in the upright position when striking the barrier and then sliding along the top of the barrier.

Motorcycle fatalities and serious injuries constitute a significant proportion of the road trauma burden in most countries and are usually one of the main focuses of national road safety strategies. Crash data analysis is finding that motorcyclists are overrepresented in terms of risk of being killed or injured per distance traveled (*1*). On average, motorcyclists are 30 times more likely to be killed and around 44 to 56 times more likely to be seriously injured than car occupants are (*2–4*).

Analyses by a number of researchers have identified a range of factors that cause motorcycle crashes and affect their severity and rider injuries. These factors are speed, age, time of year, experience, alcohol, illicit drug use, time of day, conspicuity, risk-taking behavior, roadside environment (poles and trees), and helmet use (*1, 5–16*).

Transport and Road Safety Research, First Floor, Old Main Building (K15), University of New South Wales, Sydney, New South Wales 2052, Australia. Corresponding author: R. Grzebieta, r.grzebieta@unsw.edu.au.

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This paper focuses on motorcyclist impacts into roadside barriers and the current voluntary European Standard EN 1317-8, 2010, for testing such barriers (*17–19*). This standard prescribes crash tests in which an anthropomorphic crash test dummy (ATD) is propelled head first wearing a helmet into a barrier at an angle of 30° and an impact speed of 60 km/h. Although the standard recommends ATD head, neck, and thorax instrumentation, only head and neck biomechanical indices are defined for determining the injury severity levels of barrier crashes. However, research has shown evidence that motorcyclists have sustained mainly thorax injuries in these types of crashes (*1*).

Although a significant amount of research effort has gone into developing the European standard, the proportion of fatal motorcycle crashes involving roadside barriers is typically small: 5.5% in the United States (*20*), 5.4% in Australasia (*21*), and 8% to 16% in Europe (*4*). However, barriers represent a much greater fatality risk to motorcyclists than to car occupants; the risk to motorcyclists is 15 times greater than to car occupants in Europe (*4*) and 80 times greater for steel guardrails in the United States (*20*). Gabler (*20*) determined that 12% of motorcyclist–guardrail collisions were fatal and 7.9% of motorcycle–concrete barrier collisions were fatal. The fatality risk for motorcycle–guardrail collisions was found to be 2.5 times that for motorcycle–car collisions.

Selby (*22*) found that of nonurban motorcycle crashes in New Zealand between 2001 and 2005, 6.4% of motorcycle–barrier crashes were fatal, which was slightly less than the fatality rate of 7.3% for crashes that did not involve a roadside object. Ouellet (*23*) found that in the United States, 30% of motorcyclists who hit a guardrail received at least one injury that rated 3 or greater on the abbreviated injury scale (AIS3+). Some researchers have found that impacts with roadside barriers and other stationary objects increase the likelihood of serious injury compared with other crash modes. Savolainen and Mannering (*14*) observed in the United States that motorcyclists colliding into a guardrail reduced the likelihood of minor or no injury. Quddus et al. (*24*) observed 241% and 480% increases in the probability of serious injury and fatal injury, respectively, for motorcyclists associated with a collision with a stationary object in Singapore (relative to crashes where no collision occurred). Quddus et al. also recorded a decrease in the probability of a slight injury. Relative to single-vehicle crashes for motorcyclists, injury and damage severity was found to be greatest when colliding with a stationary object.

Ruiz et al. (*19*) studied the crash mechanics of motorcycle–barrier crashes and reported a mean collision angle with metal barriers of 13° and a mean barrier impact speed of 100 km/h among fatal crashes.

Ruiz et al. found that impacts into barriers occurred equally often in the upright posture as in the sliding posture.

Berg et al. (*25*) showed that in 51% of 57 barrier cases, the motorcyclist struck the barrier while driving in an upright position; 45% of the impacts occurred where the motorcycle slid on its side on the road surface before it first struck the barrier; and in the remaining 4% of the crashes, the motorcyclist struck the barrier driving in an inclined position. Quincy et al. (*26*) reported that in 58% of barrier crashes, the motorcyclist was in the sliding posture and in 42% of the crashes struck the barrier without sliding.

Peldschus et al. (*18*) determined that in around three-quarters of collisions with fixed objects, the motorcyclist was in the upright position and the collisions typically occurred at shallow angles, with 13 crashes at less than 15°, two between 15° and 30°, and three between 30° and 45°. Bryden and Fortuniewicz (*27*) reported that among 83 barrier crashes in the United States, 60% of motorcyclists were redirected, 27% were stopped in contact with the barrier, 5% went under the barrier, and 5% went over the barrier.

Although many studies have reported on injuries associated with motorcycle crashes, most studies have reported results from data sets that include all modes of motorcycle crashes (single and multivehicle crashes) (*1*). Few studies have reported on injuries specifically associated with motorcycle–barrier crashes. The motorcycle accidents in-depth study (*28*) examined injuries occurring only among motorcyclists that collided with a roadside barrier; the study provided details on 60 injuries. However, the study did not provide the number of motorcyclists with injuries, and the study excluded from the results injuries to the thorax area; therefore, the data were inconclusive.

Peldschus et al. (*18*) reported injury profiles from a European study of motorcycle collisions with roadside infrastructure (COST 327). However, the project included only crashes in which a head or neck injury or impact occurred and was therefore biased toward such injuries. The project did show, nevertheless, that thorax injuries occurred in more than 50% of motorcycle collisions involving road infrastructure and barriers and in which the motorcyclist received a head or neck injury. The report also highlighted the injury risk to motorcyclists of striking guardrail posts and metal barrier edges.

This paper presents the results of a recent study that investigated the crash mechanics and injury profiles associated with the 78 fatal motorcycle–barrier crashes that occurred in Australia and New Zealand between 2001 and 2006 (*1*). Barrier types, crash postures, precrash speeds, impact trajectory angles, and motorcyclist kinematics, injuries, and injury severities were analyzed and quantified. The paper's main focus is on how these results would affect the development and adoption of a motorcyclist-into-roadside-barrier crash test standard that could be adopted by countries outside the European Union, such as Australia, the United States, or any Asian country. It is suggested that the current European standard provides inadequate test information on the crashworthiness of roadside barriers.

DATA COLLECTION AND ANALYSIS

Two reports have described the methodology of how the data were collected and analyzed for this study (*1, 8*). Roadside fatalities involving a motorcycle were identified in the Australian National Coroners Information System (NCIS) and the Crash Analysis System of the New Zealand Transport Agency for 2001 to 2006. Fourteen hundred sixty-two roadside motorcycle fatality cases were identified. Of those, 78 cases were positively identified as involving a roadside safety barrier. The police reports contained varying amounts of information. However, according to police procedure for fatal crashes, in most cases police crash team investigators were in attendance at the crash scene. Scene photographs were available in 66 case files, measurements of the crash scene were documented in 62 cases (skid or scrape mark lengths, location of impact points, resting positions of motorcycles and motorcyclists, etc.), the precrash speed of the motorcycle was estimated in 54 cases, and scene diagrams produced from a surveying instrument were included in 14 cases. Many cases also included witness accounts and statements from police attending the scene (*8, 21, 29, 30*).

The rigid upright posts of some barrier systems have been previously noted to be particularly harmful to motorcyclists (*18, 23*). Thus, in the present study, the involvement of posts was documented. Post impacts were determined in the files from the on-scene crash investigators' reports of markings and in some cases were complimented by witness statements. Such markings included one or more of the following: blood or human tissue on posts; helmet scrape marks on posts; clothing material caught on posts; imprints left in helmets matching post markings; and motorcyclist position when found (*1, 31*).

The crash modes are summarized in Figures 1 and 2, along with the motorcyclist kinematics and the occurrence of motorcyclist impacts with barrier posts and barrier types (*1, 31*). There were 34 confirmed post impacts, predominantly on W-beam barriers. However, two were wire-rope posts and three resulted from sign posts located on top of concrete barriers. Of the 34 impacts, 19 were in the upright posture, 13 were sliding, and two were ejected. Of the motorcyclists that struck a W-beam or wire-rope barrier post, 92% recorded AIS3+ injury to the area of the body that contacted the post, and 76% recorded a maximum abbreviated injury scale (MAIS) for the area of the body that contacted the post. The crash modes in which motorcyclists collided with the barriers were classified according to the three categories, upright (37 cases), sliding (34 cases), or ejected (5 cases). In two cases, the crash mode could not be determined.

In the sliding crash mode, the motorcycle falls to the roadway and the motorcyclist and motorcycle slide along the road surface and into the barrier. Witness reports often comment on the fact that the motorcyclist and the motorcycle are separated prior to contacting the barrier in this mode. However, a reliable criterion for establishing separation could not be established from the case files. The sliding crash mode was categorized further in some cases into cases of low-siding or high-siding. Low-siding involves the motorcycle falling to the roadway on the side of the motorcycle that is on the inside of the corner. High-siding involves the motorcycle being flipped over from the inside of the corner to contact the roadway on the outside side of the motorcycle (opposite to the leaning side). Evidence of the motorcycle low-siding or high-siding could be determined in 23 of the sliding cases, from the skid and scrape marks on the roadway or the damage to the motorcycle (*1, 31*).

In the upright crash mode, the motorcyclist is in the upright posture and collides with the barrier while seated on the motorcycle. The motorcycle is typically redirected along the barrier. Due to the impact trajectory angle of the motorcycle relative to the barrier, momentum causes the upper body of the motorcyclist to continue over the barrier. In nine cases, the motorcyclist was ejected over the barrier upon impact. In 20 cases, this momentum and the redirection of the motorcycle along the barrier resulted in the motorcyclist scraping, tumbling, or skidding along the top of the barrier. After scraping along the top of the barrier for some distance, the motorcyclist was then ejected from the barrier; in 15 of the 20 cases, this occurred as a result of the motorcyclist impacting a barrier post.

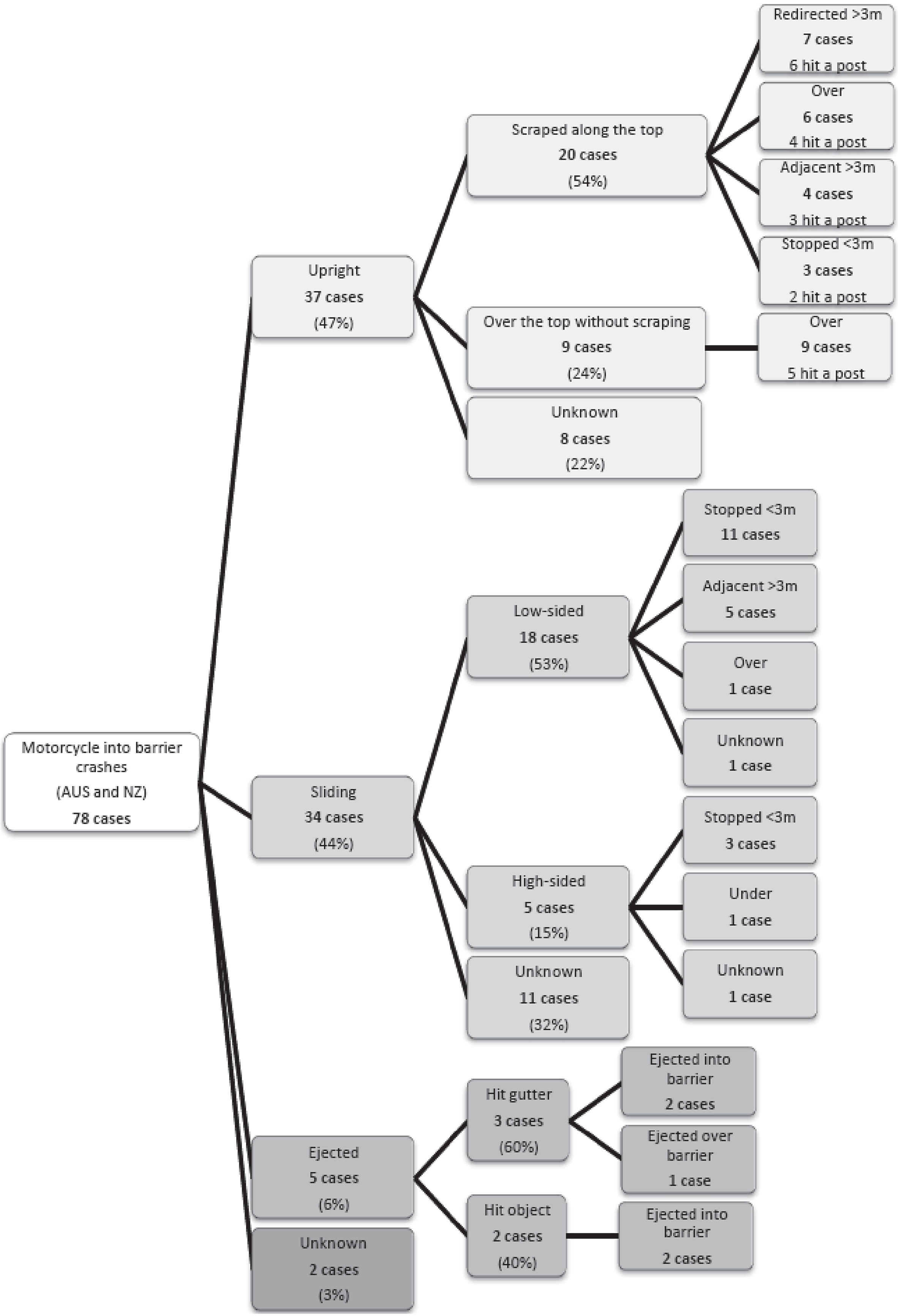


FIGURE 1 Crash modes, motorcyclist kinematics, and guardrail impacts with post for 78 motorcycle-into-barrier impacts (AUS = Australia; NZ = New Zealand) (*1*, *31*).

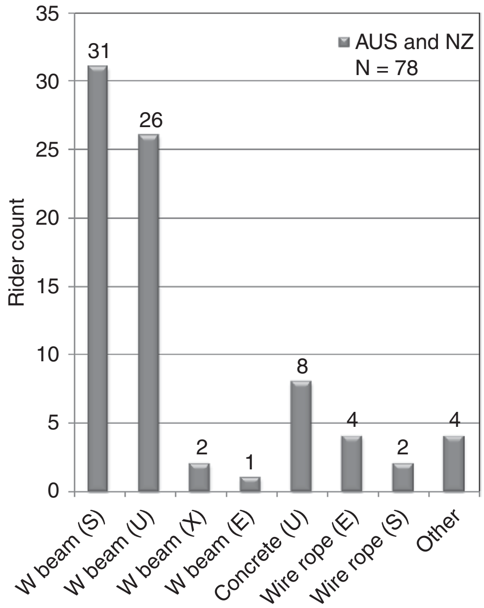


FIGURE 2 Barrier types and crash postures (*1, 31*) (S = sliding posture; U = upright posture; X = unknown posture; E = ejected).

The extent to which the motorcyclist remained in contact with the motorcycle during the process of scraping along the top of the barrier could not be determined from the case files. Some crash tests in the upright mode have shown that ATDs may separate from the motorcycle during this process (*18, 25*). In eight cases, whether the motorcyclist had scraped along the top of the barrier could not be determined (*1, 13*).

In the ejected crash mode, the motorcycle came into contact with the gutter (three cases) or an object (two cases) and the motorcycle rapidly decelerated, ejecting the motorcyclist forward from the motorcycle and into or onto the barrier. In eight cases a fatality resulted from a motorcycle collision with a concrete barrier; however, in none of those cases did the motorcyclist strike the barrier in the sliding crash mode (*1, 13*).

The mean distance the motorcyclists traveled from the impact point with the barrier was 21.8 m [standard deviation (SD) = 23.4 m] in all crash modes. Of motorcyclists that struck the barrier in the sliding crash mode, the mean distance was 12.7 m (SD = 20.6 m); in the upright mode, the mean distance was 26.3 m (SD = 20.4 m). The longer distance covered when in the upright mode resulted from the momentum retained by motorcyclists as they scraped, tumbled, or skidded along the top of the barrier. The mean distance motorcyclists scraped along the top of the barrier in the upright mode was 13.9 m (SD = 12.4 m). Given that W-beam posts are typically spaced 2 m apart, this factor presents multiple opportunities for the motorcyclist to strike a post and results in the high incidence noted in this crash mode (15 of 20 in Figure 1). The mean distance motorcyclists slid on the roadway prior to impacting the barrier in the sliding crash mode was 28.9 m (SD = 13.8 m) (*1, 13*).

The mean impact angle in all crash modes was 15.4° (SD = 8.6°), and the mean impact angles for the sliding and upright crash modes were approximately the same. Motorcyclists who went over the barrier tended to have struck the barrier at angles greater than the mean. Motorcyclists who were redirected tended to have struck the barrier at angles less than the mean; both results would be expected considering the momentum of the motorcyclist (*1, 13*).

Figure 3*a* plots the percentage of motorcyclists who received at least one AIS3+ injury in each body region among the group of motorcyclists who collided with W-beam barriers, and the motorcyclists who collided with W-beams in the sliding posture or the

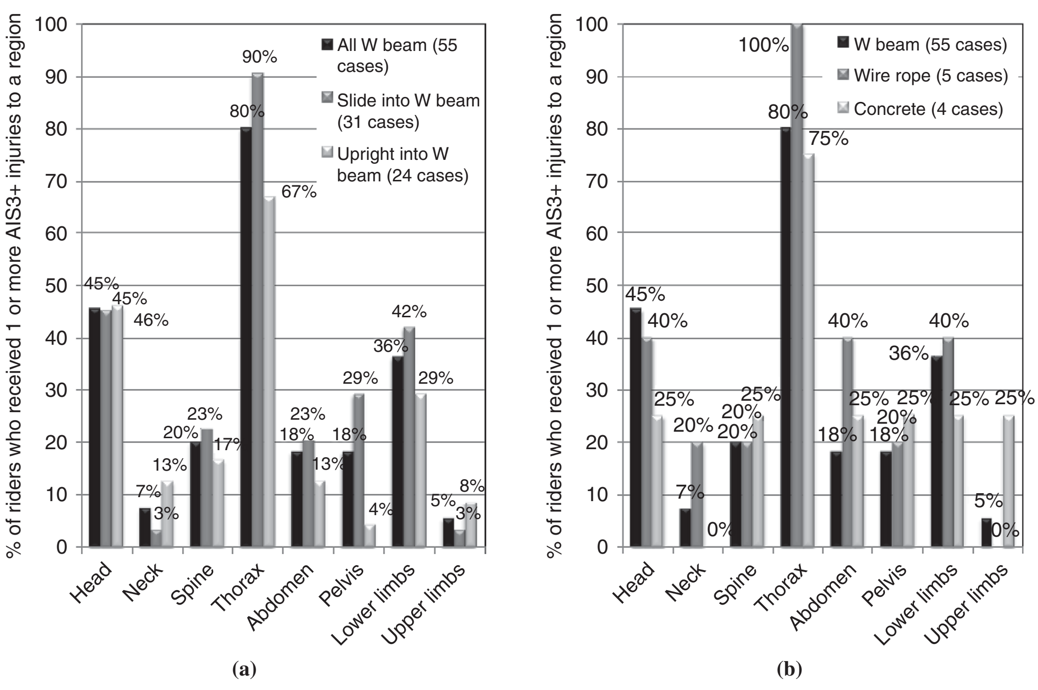


FIGURE 3 Injury profiles for (*a*) crash postures in collisions with W-beams and (*b*) barrier types in all crash postures (*1*).

upright posture. Although the injury profiles of the two crash postures were similar, thorax and pelvis injuries occurred more frequently among motorcyclists who slid into W-beam barriers. Figure 3*b* compares the injury profiles for the three barrier types, W-beam, wire rope, and concrete. The distribution of injuries is quite similar. However, the results must be treated cautiously because the data sets were small for the wire-rope and concrete barriers (five cases and four cases, respectively) (*1, 13*).

MOTORCYCLE–BARRIER CRASH TEST PROTOCOLS

European standards have recently been developed that define methods for evaluating the performance of barriers when struck by a motorcyclist (*17, 20*). These standards prescribe crash tests in which an ATD is propelled into a barrier at an angle of 30° and an impact speed of 60 km/h. Although the standards recommend ATD head, neck, and thorax instrumentation, only head and neck biomechanical indices are defined for determining the injury severity levels of the barrier crash.

For comparison of injury profiles resulting from conditions similar to those prescribed by these standards, those cases in which the impact speed of a sliding motorcyclist was likely to be around 60 km/h were determined and are presented in Table 1. Lower-bound impact speeds were determined by using the lower-bound precrash speed and upper-bound drag factor, and upper-bound speed was determined by using the upper-bound precrash speed and lower-bound drag factor to produce the impact speed ranges listed in Table 1 (*1*). In this group of 11 fatally injured motorcyclists were 31 thorax, six abdominal, six lower extremity, three spine, two head, and one upper extremity AIS3+ injuries. The thorax received an MAIS injury in nine of the 11 cases. Because the number of motorcyclists and the nature of the injuries of motorcyclists who collided with a barrier at this speed and were not fatally injured were unknown, an injury or fatality risk could not be determined. However, from Table 1 it is clear that such collisions can certainly be fatal. When motorcyclists were fatally injured in such collisions, the injury was generally from thorax injury rather than head or neck injury.

This result has significant implications for motorcyclist–barrier testing protocols and the development of barrier systems that would mitigate the risk of such injuries. Although some researchers have suggested a thorax injury criterion, presently no such criteria have been adopted because of concerns about the biofidelity of current ATD thoraxes and inconclusive relationships between measured loads and injury severity (*17–20, 32*). Bambach et al. (*1*) have provided two alternative sliding tests. However, more research needs to be carried out to assess the viability of these and other scenarios.

Considering that a quarter (20) of the cases (Figure 1) involved an upright rider sliding along the top of the barrier, another test should also be considered in regards to addressing injuries occurring in motorcycle–barrier crashes. Figure 4 shows the top of a standard W-beam barrier, where it can be clearly seen how the Charlie posts and C section blockout protrude above the top of the beam. At high speeds, these posts and blockouts act as sharp cutting edges much like a hacksaw.

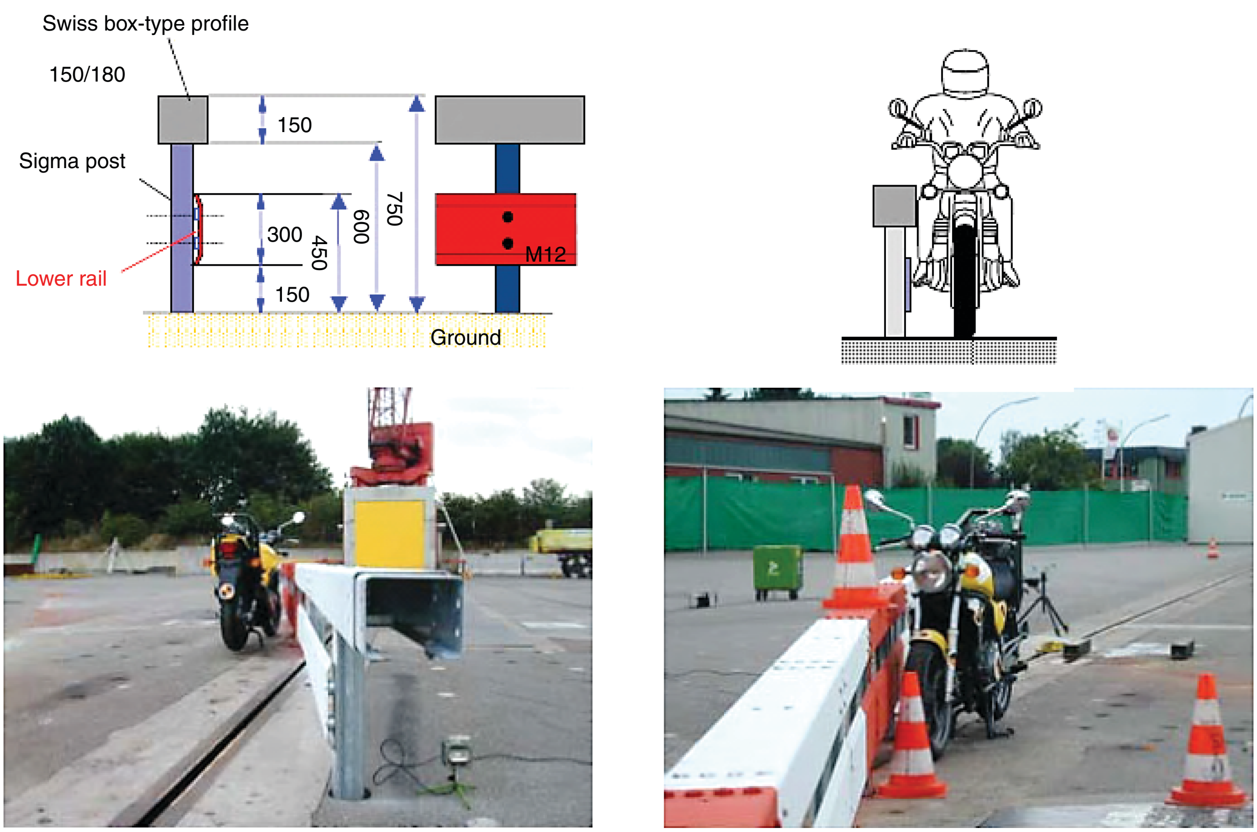
In addition to addressing the measurement of thorax injury risk, the European test (*1, 17–19, 32*) should require that an ATD slide along the top of the barrier. An alternative design and test procedure proposed by Berg et al. in 2005 (*25*) is shown in Figure 5. Although most of the cases discussed concern W-beam barriers, this box beam example is presented here to illustrate how a barrier can be manufactured to be safer for motorcyclists in terms of reducing snagging points

TABLE 1 Crashes in Which Motorcyclist Was Likely to Be Traveling in Sliding Posture at 60 km/h on Impact with Barrier (*1*)

Barrier Type	Angle (°)	Barrier Impact Speed Range (km/h)	Injury Severity Score	MAIS	MAIS Body Region	AIS3+ Injuries
W-beam	NA	80[a]	25	4	Thorax	≥3 ribs fractured, lacerated aorta, ruptured diaphragm, hemopneumothorax, pelvic ring fracture
W-beam	NA	27–64	75	6	Thorax	≥3 ribs fractured, ventricular rupture of heart, major hemothorax, major spleen laceration, cerebrum subdural hematoma
W-beam	16	49–66	75	5	Thorax, spine	Bilateral flail chest, perforated heart, hemothorax, cervical cord laceration, lumbar cord laceration
Wire rope	24	32–65	16	4	Thorax	≥3 ribs fractured, major hemothorax
W-beam	19	26–63	43	5	Spine	Thoracic cord laceration with fracture, hemothorax, intracerebral hematoma, femur fractures
W-beam	18	29–66	18	3	Thorax, lower extremities	≥3 ribs fractured, major unilateral lung contusion, unilateral lung laceration, hemothorax, open tibia shaft fracture
W-beam	9	61–82	9	3	Thorax	≥3 ribs fractured, hemothorax
W-beam	10	59–83	32	4	Thorax, upper extremities	≥3 ribs fractured, lacerated aorta, unilateral lung laceration, hemothorax, arm amputation at shoulder
W-beam	14	60[a]	16	4	Thorax	≥3 ribs fractured, bilateral lung contusion, major pneumothorax
W-beam	28	46–62	41	5	Abdomen	Unilateral flail chest with >5 ribs fractured, major unilateral lung laceration, ruptured diaphragm, stomach, uterus and spleen, renal artery and vein lacerations, major hemothorax
W-beam	32	55–77	18	3	Thorax, lower extremities	≥3 ribs fractured, both femurs fractured

NOTE: NA = not available.
[a]Precrash speed shown since slide measurements were not available.

FIGURE 4 W-beam with Charlie post and blockout.



(a) (b)

FIGURE 5 Steel barrier with (*a*) lower rub rail and (*b*) smooth top [after Berg et al. (*25*)].

and cutting edges. This example is also introduced to demonstrate how an upright test could possibly be carried out.

Thus, two test procedures should be implemented. The first would be the current European Standard EN 1317-8 regulation, and the second would require the rider ATD to slide along the top of the barrier. Moreover, chest injury criteria should be adopted, such as maximum *g* levels (9.81 m/s^2) of around 60 *g*'s and chest compression injury criteria commonly adopted for side and frontal impact crashes. The adoption of thorax injury criteria would also provide an opportunity for the design of roadside furniture poles and signs and motorcycle impact cushioning systems and padding that could reduce the severity of impacts.

CONCLUSIONS

In the Australian and New Zealand data, the majority of motorcycle-into-barrier crashes have resulted from collisions with steel W-beam barriers. A similar situation exists in the U.S. data (*20*).

Both sliding and upright crash postures were approximately equally represented. The mean precrash speed was 100.8 km/h and the mean impact angle was 15.4°. The thorax region was found to have the highest incidence of injury and the highest incidence of maximum injury in fatal motorcycle-into-barrier crashes; the second-highest was the head region. Because existing motorcycle–barrier crash testing protocols do not specify thorax injury criteria, there appears to be a need to establish such criteria not only for barrier impact testing but also for the development of road furniture and impact attenuation devices for reducing impact injuries suffered by motorcyclists.

Approximately a quarter of the motorcycle crashes in the study data involved an upright crash posture with the rider subsequently sliding and tumbling along the top of the barrier. An additional test should be developed, possibly similar to the DEKRA (German Motor Vehicle Inspection Association) test proposed by Berg et al. (*25*), which requires the rider to be in an upright position when striking the barrier and then slide along the top of the barrier. Berg et al. (*25*) further proposed that a rub rail along the bottom of the barrier and a smooth surface along its top would reduce motorcycle-into-barrier injuries. The study reported here called for future research and development of such a standard in Australia.

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