

**Effectiveness of Antilock Braking Systems  
in Reducing Fatal Motorcycle Crashes**

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## **Abstract**

The effect of antilock braking systems (ABS) on motorcyclist fatal crash risk during 2003-07 was studied by comparing fatal crash rates per registrations of motorcycles with and without ABS. Study motorcycles included those for which ABS was optional equipment and could be identified as present by the vehicle identification number. Fatal motorcycle crashes per 10,000 registered vehicle years were 28 percent lower for ABS models than for their non-ABS versions.

**Keywords:** Motorcycles; Crashes; Antilock braking system; Combined braking systems; Wheel lock; Insurance claims

## **1. Introduction**

Annual motorcyclist deaths in the United States have more than doubled, from 2,077 in 1997 to 5,037 in 2007 (Insurance Institute for Highway Safety, 2007), and motorcycle registrations have increased by about two-thirds, from 5,167,693 in 2000 (earliest year for which data are available) to 9,201,235 in 2007, according to data obtained from R.L. Polk and Company. Many factors contribute to motorcycle crashes, but improper braking was identified as a major preimpact factor in a study of motorcycle crash causation (Hurt et al., 1981) and again, 20 years later, in the Motorcycle Accident In-Depth Study (MAIDS) (Association of European Motorcycle Manufacturers, 2004).

Operating the brakes on most motorcycles is much more complicated than on four-wheel vehicles. Most motorcycles have separate controls for the front and rear brakes, with the front brake usually controlled by a lever on the right handlebar and the rear brake controlled by a pedal operated by the rider's right foot. During braking, a rider must decide how much force to apply to each control. As with other types of vehicles, much more deceleration can be obtained from braking the front wheel than from braking the rear wheel.

Motorcycles are inherently less stable than four-wheel vehicles and rely on riders' skills to remain upright during demanding maneuvers such as hard braking. Braking too hard and locking a wheel creates an inherently unstable situation. Locking the front wheel is particularly dangerous, with capsizing being

almost certain. A locked rear wheel is more controllable but still can lead to loss of control if the rider simultaneously tries to steer the motorcycle, as in an emergency avoidance maneuver. In such situations, riders concerned about wheel lock may be reluctant to apply full force to the brakes, particularly to the front brake, resulting in braking that is not adequate to avoid impact. Both Hurt et al. (1981) and MAIDS (Association of European Motorcycle Manufacturers, 2004) had examples of both loss of control due to wheel lock and failure to adequately brake.

Although proper braking practices can be taught, rider training courses have not been shown to be effective in reducing motorcycle crashes or have provided mixed results at best (Billheimer, 1998; Mayhew and Simpson, 1996). To address the issue of underbraking (especially the front wheel), manufacturers have developed braking systems that essentially link the actions of the front and rear brake controls. These systems, referred to collectively here as combined braking systems (CBS), apply braking force to both wheels when either control is engaged. The degree to which braking force is applied to the front wheel, for example, when the pedal for the rear brake is depressed varies by design, but the concept is the same. CBS has been shown to reduce stopping distances of experienced riders on closed test tracks (Green, 2006) and would be expected to be beneficial in situations in which a rider underbrakes (or does not brake) the front wheel to avoid locking it or causing the motorcycle to pitch forward. Even with CBS, however, it still is possible to lock a wheel during hard braking, often with catastrophic consequences.

ABS has been adapted and tuned for motorcycles to help riders solve this dilemma. Antilock braking systems monitor wheel speed and reduce brake pressure when impending wheel lock is detected. Brake pressure is increased when traction is restored, and the system evaluates and adjusts brake pressure many times per second. These systems allow riders to apply brakes fully in an emergency without fear of wheel lock. ABS was first developed for commercial aircraft in 1929 (Maslen, 2008) and was first implemented in production automobiles with the 1971 Chrysler Imperial (Douglas and Schafer, 1971). BMW was the first manufacturer to implement ABS on a motorcycle with its K100RS Special model in 1988 (Tuttle, 2001). ABS and CBS are not necessarily related; either or both can be implemented on a motorcycle.

ABS has not significantly reduced crash risk for passenger vehicles (Farmer, 2001; Farmer et al., 1997), but there is reason to expect ABS will be more helpful to motorcycles because of the instability that occurs when either wheel locks. Studies conducted on closed test tracks have demonstrated that ABS can reduce motorcycle stopping distances (Green, 2006; Vavryn and Winkelbauer, 2004). It is clear that reducing wheel lock is crucial in maintaining stability during hard braking. These results suggest that ABS has the potential to reduce motorcycle crashes in real-world situations. Serious motorcycle crashes identified from insurance liability claims were analyzed in a small study to determine, by crash reconstruction, how certain crashes would be affected by ABS (Gwehenberger et al., 2006). About half of the 200 crashes studied were deemed to be relevant to ABS, and the majority of those involved another vehicle violating a motorcyclist's right-of-way. Crash reconstruction analyses showed that between 17 and 38 percent of the crashes deemed to have been ABS relevant could have been avoided had the motorcycles been equipped with ABS. No results were presented on how increased stability or stopping power provided by ABS might have reduced the severities of the crashes that were deemed inevitable.

A study by the Highway Loss Data Institute (HLDI), conducted in conjunction with the present study, found that motorcycles equipped with optional ABS had 19 percent fewer insurance claims for collision damage per insured vehicle year than the same motorcycle models without ABS (Moore and Yan, 2008). The goal of the present study was to evaluate the effectiveness of ABS in reducing the rate of fatal motorcycle crashes on public roads. Specifically, rates of fatal crash involvement per registered vehicle were compared for the same motorcycle models as those included in the HLDI study, with and without ABS installed as optional equipment.

## **2. Methods**

Data on fatal motorcycle crashes were extracted from the Fatality Analysis Reporting System (FARS), a national census of fatal crashes occurring on public roads that is maintained by the National Highway Traffic Safety Administration. Exposure data consisted of national motorcycle registration records obtained from R.L. Polk and Company. Each vehicle record in both databases was indexed by its

vehicle identification number (VIN), which encodes vehicle information, and the first 10 digits of the VINs were used to determine make, model name, and model year according to records in a motorcycle features database created and maintained by HLDI. Vehicles with missing or invalid VINs were excluded.

To be included in the study, a motorcycle model was required to have ABS as an option, and the presence of that option must have been discernable by the presence of a VIN ABS indicator or equivalently from the model name (e.g., Honda Gold Wing vs. Honda Gold Wing ABS). This eliminated bias due to the comparison of different makes or, especially, styles of motorcycles, the driver death rates of which have been shown to vary widely (Insurance Institute for Highway Safety, 2009). Although ABS has been an option on BMW models for much longer than the study period, BMW does not use a VIN indicator for ABS. All BMW models were excluded. The final study population (Table 1) included eight make/model motorcycles, each with both ABS and non-ABS versions. Some vehicles were excluded due to zero registrations of the ABS model during the study years in the Polk records. Because none of the study vehicles with ABS were available in model year 2000 or earlier, the entire analysis was restricted to 2001 or later model year vehicles. For each motorcycle model, model years were held identical for both ABS and non-ABS versions. Among the motorcycles included, all of the Hondas (both ABS and non-ABS) were equipped with standard CBS; CBS was not available on any of the other motorcycles.

At the time this study was conducted, registration data were available only for 2000 and 2003-07, and FARS data were available through 2007. There were no registrations of the ABS versions of these motorcycles in 2000. Therefore, data were analyzed for years 2003-07. Fatal crash rates per 10,000 registered vehicle years for each motorcycle model, both ABS and non-ABS versions, were calculated by dividing 10,000 times the number of motorcycle driver fatal crash involvements during 2003-07 by the number of motorcycles registered during these years. Because registration counts spanned 5 years, the denominator was interpreted as registered vehicle years instead of as the number of registered vehicles.

Fatal crash rates per vehicle registrations for ABS and non-ABS motorcycle models were compared by estimating a rate-ratio (RR) equal to the crash rate for ABS models divided by the crash rate

for non-ABS models. If ABS has no effect, then the rate-ratio should be 1.0. A rate-ratio less than 1.0 would indicate the fatal crash rate for ABS models is lower than the rate for non-ABS models. Similarly, a rate-ratio greater than 1.0 would indicate the fatal crash rate for ABS models is higher than the rate for non-ABS models. One way to estimate the rate-ratio is to calculate the rate for non-ABS motorcycles as total crash involvements divided by total registered vehicle years, and analogously for ABS motorcycles. However, to reduce any bias that may have occurred from relative differences in registrations among motorcycle models, an alternative rate for non-ABS motorcycles was calculated as the weighted average of fatal crash rates for each vehicle model, where the weights were taken as the number of registered vehicle years of ABS motorcycles. Thus, for any given motorcycle model the ABS and non-ABS fatal crash rates received the same weight in calculating the overall fatal crash rates for motorcycles with and without ABS.

Ninety and 95 percent confidence intervals (CIs) for the rate-ratios were calculated based on standard error estimates derived by assuming that the number of fatal crash involvements follows a Poisson distribution as follows:

$$\text{Var}(\ln(\text{RR})) = \text{Var}_{\text{ABS}} + \text{Var}_{\text{non-ABS}}$$

$$\text{where } \text{Var}_{\text{ABS}} = \frac{1}{\sum_{i=1}^{10} r_i X_{i,\text{ABS}}} \text{ and } \text{Var}_{\text{non-ABS}} = \frac{\sum_{i=1}^{10} r_i^2 X_{i,\text{non-ABS}}}{\left(\sum_{i=1}^{10} r_i X_{i,\text{non-ABS}}\right)^2}$$

with  $X_{i,\text{ABS}}$  as the number of fatal crash involvements of the  $i^{\text{th}}$  model motorcycle equipped with ABS, analogously for  $X_{i,\text{non-ABS}}$ , and  $r_i$  as the ratio of registered vehicle years of the ABS model to registered vehicle years of the non-ABS model for model  $i$ .

Assuming asymptotic normality of  $\ln(\text{RR})$  gives:

$$\text{lower 95\% confidence limit} = \exp[\ln(\text{RR}) - 1.96(\text{Var}(\ln(\text{RR})))^{1/2}]$$

$$\text{upper 95\% confidence limit} = \exp[\ln(\text{RR}) + 1.96(\text{Var}(\ln(\text{RR})))^{1/2}]$$

The 90 percent confidence interval was derived analogously, except that 1.645 was substituted for 1.96.

In addition to the main analysis, information was extracted from FARS describing driver age, speeding behavior, blood alcohol concentration (BAC), number of involved vehicles, helmet use, and

crash location (rural vs. urban) for ABS and non-ABS groups. Missing values of BACs were estimated using multiple imputation results available in FARS. Speeding was coded if the motorcycle driver was cited for speeding, or if contributing factors indicated the motorcycle was exceeding the posted limit or was traveling too fast for conditions. Helmet law type — universal coverage, partial coverage in which only some riders (usually those below a certain age) must wear helmets, and no law — was coded for the state in which a crash occurred, and varied by year with changes in laws.

### **3. Results**

Table 2 presents fatal crash involvements, registered vehicle years, and the rate of fatal crash involvements per 10,000 registered vehicle years for the study motorcycles during 2003-07. Motorcycles manufactured by Honda, particularly the Gold Wing model, dominated the sample, but the pattern for all but three of the motorcycles was a lower fatal crash rate for ABS motorcycles. Across all ABS motorcycles, the rate of fatal crash involvements per 10,000 registered vehicle years was 4.6, compared with 6.4 for the same motorcycles not equipped with ABS.

The effect of ABS on fatal crash involvement is given by the rate-ratio estimate for ABS motorcycles against non-ABS motorcycles. This estimate and associated 90 and 95 percent confidence intervals are provided in Table 3. The rate-ratio estimate corresponds to an approximate 28 percent reduction (computed as  $(RR-1) \times 100\%$ ) in the rate of fatal crash involvements per 10,000 registered vehicle years for the ABS models over the (weighted) non-ABS models.

Influences on the observed rate-ratio of known risk factors for fatal motorcycle crashes were investigated by comparing their distributions among ABS motorcycles and non-ABS motorcycles included in the study, as summarized in Table 4. The average driver age for non-ABS motorcycles was 54, compared with 50 for ABS motorcycles. Drivers of non-ABS motorcycles were slightly more likely than drivers of ABS motorcycles to have been cited for speeding or alcohol impairment at the time of their fatal crashes. However, they also were more likely to have been helmeted, a difference not clearly explained by helmet laws in the states in which they were travelling. In other words, there was little

difference in the distribution of helmet laws between ABS and non-ABS motorcycle drivers (Table 4) and the effect of helmet laws on helmet use did not substantially differ between the two groups (data not shown). No substantial difference between the two groups was observed in the likelihood of single-vehicle crashes or of rural crash locations.

#### **4. Discussion**

Results of this analysis provide evidence that ABS is effective in reducing fatal motorcycle crashes. Study motorcycles with ABS had a fatal crash involvement rate 28 percent lower than that for their non-ABS versions during the study years.

Although the estimated effect of 28 percent is large, it is not statistically significant at the customary 0.05 level. ABS is a relatively recent option on motorcycles, and the option was purchased on only 21 percent of registered study vehicles during 2003-07. More data are required to obtain a more precise estimate of ABS effectiveness in reducing fatal motorcycle crashes. However, as the estimate becomes more precise, it is quite likely that it will continue to indicate a benefit of ABS. If there was no effect of ABS on fatal crash involvement, an estimate as large as the 28 percent reduction in this study would be expected to occur by chance less than 10 percent of the time. Thus, there is considerable confidence that ABS is preventing fatal crashes among motorcyclists. This confidence is bolstered by the fact that a separate analysis of insurance collision coverage losses among crashes of all severities also shows a reduction in crashes of about 19 percent for motorcycles equipped with ABS (Moore and Yan, 2008). These results provide confirmatory evidence of the expected benefit of ABS from engineering principles, test-track trials, and a crash reconstruction analysis.

The substantial effectiveness estimate observed in this study is not, however, without limitations. ABS was studied as optional equipment, so the cohort of motorcyclists who choose to purchase ABS may differ from those who decline to purchase it. In particular, motorcyclists who choose ABS may be more concerned about safety than those who decline, thus leading to lower fatal crash rates due to safer riding practices. Investigation of known risk factors did not find evidence of such a bias. However, levels of

these factors were not known for riders who were not involved in fatal crashes. Therefore, it was not possible to accurately quantify how such factors influenced the observed reduction in fatal crash rate for ABS motorcycles. It is also possible, however, that riders who choose ABS accumulate more miles than those who decline, which would result in an upward bias in the fatal crash rate for the ABS cohort relative to the non-ABS cohort. As purported to occur in passenger vehicles (Grant and Smiley, 1993), motorcyclists may tend to drive ABS motorcycles more aggressively than non-ABS motorcycles, also resulting in a higher than expected crash rate for the ABS group. Without more extensive data, it was not possible to know the magnitude or nature of any bias of the estimated rate-ratio comparing crash rates for ABS and non-ABS motorcycles.

With or without ABS, CBS also may reduce the likelihood of certain types of crashes. However, due to the small sample of non-CBS motorcycles in this study, the effect of CBS could not be evaluated. Still, CBS is not expected to bias the results because the braking systems of the ABS and non-ABS motorcycles differed only by whether or not they were equipped with ABS. In other words, each ABS/non-ABS pair either did or did not have CBS, making the effect of CBS orthogonal to that of ABS in the present study. ABS showed a benefit in both the CBS and non-CBS groups, suggesting the presence of CBS on some of the motorcycles did not confound the observed effect of ABS.

ABS cannot be expected to prevent or mitigate all types of crashes, as demonstrated by Gwehenberger et al. (2006). For example, ABS would not affect the likelihood or outcome of a crash involving a motorcycle struck from behind by another vehicle. The small sample of ABS motorcycles and the lack of detailed information on precrash events in FARS precluded examination of the effects of ABS on crashes that would or would not likely have been influenced by its presence.

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Table 1  
Study motorcycles, each with ABS and non-ABS versions in these model years

Make/model	Model years
Honda Gold Wing	2001-08
Honda Interceptor 800	2002-07
Honda Reflex	2001-07
Honda ST1300	2003-07
Honda Silver Wing	2003-07
Suzuki Bandit 1250	2007
Suzuki Burgman 650	2006-07
Suzuki SV650	2007
Triumph Sprint ST	2006-07
Yamaha FJR1300	2004-05

Table 2  
Motorcycle fatal crash involvements and registered vehicle years, 2003-07

	Non-ABS models			ABS models		
	Fatal crash involvements	Registered vehicle years	Rate (x 10,000)	Fatal crash involvements	Registered vehicle years	Rate (x 10,000)
Honda Gold Wing	121	208,376	5.8	20	48,712	4.1
Honda Interceptor 800	16	19,851	8.1	6	5,259	11.4
Honda Reflex	14	34,086	4.1	2	6,127	3.3
Honda ST1300	7	15,258	4.6	4	7,603	5.3
Honda Silver Wing	11	16,839	6.5	2	2,737	7.3
Suzuki Bandit 1250	2	516	38.8	0	132	0.0
Suzuki Burgman 650	4	4,039	9.9	0	1,133	0.0
Suzuki SV650	4	1,793	22.3	0	39	0.0
Triumph Sprint ST	2	701	28.5	1	606	16.5
Yamaha FJR1300	9	9,599	9.4	3	9,441	3.2
Total	190	311,058	6.4*	38	81,789	4.6

\*Overall non-ABS rate is weighted by registered vehicle years of ABS motorcycles.

Table 3  
 Estimated rate-ratio and confidence intervals for  
 comparing ABS and non-ABS fatal crash rates

Rate-ratio	95% confidence interval	90% confidence interval
0.722	(0.504, 1.036)	(0.534, 0.977)

Table 4  
 Driver and crash factors of study motorcycle drivers

	Non-ABS models		ABS models	
	N	%	N	%
Drivers				
Age <30	10	5	2	5
Age 30-39	18	9	4	11
Age 40-49	34	18	11	29
Age 50+	128	67	21	55
Who were speeding	43	23	7	18
With BAC $\geq$ 0.08 g/dl	34	18	5	14
Who were helmeted	140	74	26	68
Crashes				
Single-vehicle crash	77	41	16	42
Rural crash location	129	67	24	63
Universal helmet law	69	36	16	42
Partial helmet law	108	57	19	50
No helmet law	13	7	3	8
Total	190		38	