

Article

All-Terrain Vehicle Safety—Potential Effectiveness of the Quadbar as a Crush Prevention Device

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Abstract: A total of 10,561 all-terrain vehicle (ATV) related deaths have been documented for the years 1985 through 2009 in the United States, most of which were associated with overturns of the machine. The current analysis addresses the question, “How effective is the Quadbar™ (QB) as a crush prevention device (CPD) in preventing ATV overturn-related injuries?” A CPD is designed as a guard against crushing injuries to the ATV rider in the event of an overturn. The analysis used a prevention effectiveness model to address this question. Based on this analysis, the CPD and more specifically the QB were found to potentially prevent serious injuries and death to ATV riders that result from overturns. Systematic real-life studies are needed to evaluate the prevention potential of CPDs that are in use to guide the implementation of policies to better protect the public from these injuries.

Keywords: All-terrain vehicle; ATV; Quad Bike; Crush Prevention Device; crashworthiness; overturns; rollovers

1. Introduction

“We would far prefer to adopt only standards that pose no problem to anyone and that do not require any active cooperation on the part of the user. This is the approach that has been used in public health . . . ” —Dr. William Haddon, Jr. 1967 [1].

In 1987, the U.S. Consumer Product Safety Commission (CPSC) concluded that all-terrain vehicles (ATVs) were an “imminently hazardous consumer product.” [2] ATV overturns are the highest cause of death associated with crashes of these machines [3]. This is a serious problem, as reflected in a 2013 annual report regarding ATV-related injuries in the United States in which the CPSC documented a total of 10,561 ATV-related deaths for the years 1985 through 2009. The lowest number of deaths occurred in 1993 when 183 people were killed, but since then, there was a steady rise in the number of ATV-related deaths annually to 832 killed in 2006 and 2007 as shown in Figure 1 [4]. The dip in fatalities in 2008 and 2009 may be the result of a shift to alternative off-road vehicles. In another observation, Shultz, *et al.* reasoned that “the decline in ATV-related injuries . . . are not well understood but might be related to the economic recession of the mid-2000s and decreased sales of new ATVs.” [5] Data are still being collected on the deaths that have occurred since 2009.

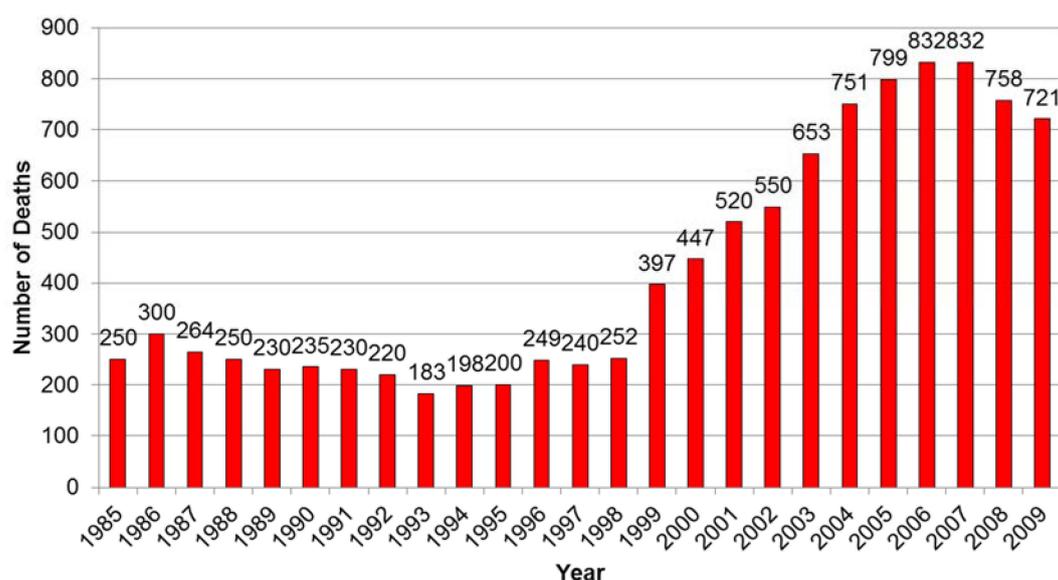


Figure 1. Number of All-Terrain Vehicles (ATV)-Related Deaths, 1985–2009, $n = 10,561$. Source: Topping and Garland, 2015 [4].

ATVs are off-road, motorized vehicles with three or four low-pressure tires, a straddle seat for the operator, and handlebars for steering control [3]. In Australia, ATVs are known as quad bikes—a four-wheel version of a two-wheeled motorcycle. They also differ in other ways: while a motorcycle was initially designed for on-road operation, the ATV is designed as an off-road vehicle [6]. In his 2009 study, Snook found several overturn characteristics of ATVs (verbatim) [7]: “At low speeds on horizontal ground, there is a strong tendency for quad bikes to rollover sideways to an upside down position. If the rider is not thrown clear of the ATV during the rollover then there is a high probability that the rider will be trapped under the vehicle and will be at risk of crushing or asphyxiation . . . As ATV speed increases, the likelihood of the ATV remaining upside down decreases. However, at times during the roll there is little clearance between the ATV and the ground and the potential for serious injury remains high. Low speed back flip of an ATV on sloping ground demonstrates a tendency to leave the ATV in an upside down condition, with the concomitant risk of trapping the rider.”

A principle in establishing a preference ranking for preventive action in safety is known as the hierarchy of controls [8]. This hierarchy has evolved over time with an early approach recommended by Haddon as shown in Table 1 [9]. In highway safety, he focused first on passive controls that required no action by the vehicle operator for safety. These controls were to precede actions required by the operator for his or her safety, called active controls. Building on this approach, a hierarchy of controls used in product design is based on a three-tier system following the same logic: first, elimination of the hazard; second, guarding against the hazard, and third, warning of the hazard [10]. The first two tiers represent passive controls, and the third tier represents an active control. A six-tier hierarchy brought together professional safety and industrial hygiene rankings of precedence in 2011, which is useful in further defining the priorities for intervening for safety [11]. More detail is available about the history of these approaches elsewhere [12].

Table 1. Three Hierarchy of Controls Each Listed in Order of Precedence.

Control Level (ANSI/ASSE Z590.3-2011) ⁱ	Design Hierarchy ⁱⁱ	Control ⁱⁱⁱ
1 Elimination	Elimination	Prevent the Exposure (passive control)
2 Substitution		
3 Engineering Controls	Guarding	
4 Warnings (Awareness)	Warning	Mitigate the Exposure (active control)
5 Administrative Controls		
6 Personal Protection		

ⁱ ANSI/ASSE Z3590.3-2011 [11]; ⁱⁱ Wogater 2006 [10]; ⁱⁱⁱ Haddon 1974 [9]

Equipment design and redesign falls to engineers. The engineering perspective is to find ways to improve vehicle safety through design rather than relying on improved human judgement [13]. At the top of that hierarchy is first, eliminating the hazard, as when CPSC banned the three-wheeled ATVs in the United States, a strategy that attacked a threefold risk of injury from crashes that exceeded the four-wheel ATV risk of crash-related injury [14].

The second level of the design hierarchy of control is to guard against the injury, which has been the path used in protecting tractor operators from crush-related injuries in the event of an overturn [15]. Many innovations have been suggested such as a roll guard, one of which is what has been named the Johnson rollover protective structure (ROPS) [16]. Another approach was the invention of a crush prevention device (CPD) in Australia, named the “Quadbar” (QB) which is a rear mounted frame like the rear mounted and successful “Roll Gard” by John Deere in 1966 (a ROPS) [17]. It took 20 years for the John Deere innovation to become standard equipment on all farm tractors in the United States. The QB, as shown in Figure 2, is the subject of this article.

**Figure 2.** A Quadbar attached to the rear of an All-Terrain Vehicles (ATV).

Active controls are based on warnings and education. Education is useful if it reaches the user and is continually reinforced, which has no guarantee. While important for widespread awareness and ancillary to the former types of controls, this is the least effective way to prevent injuries [9]. Moreover, safety helmets are known to add significant protection for the ATV rider, but the use of the helmets remains low [18].

The ATV carries some similarities to motorcycle operation regarding posture called active riding in which the driver’s weight—an important factor in moving the center of gravity of the combined human-machine—is shifted to maintain machine stability, especially in maneuvers such as turning, negotiating hills, and crossing obstacles [19]. Active riding has been addressed at an Inquest by

Coroner Lock in Australia: “Active riding refers to the operator moving their pelvis laterally and/or longitudinally on the seat, or vertically off the seat, while keeping both hands on the handlebars and both feet on the footrests throughout a maneuver, increasing the stability of the quad bike (ATV), and thereby reducing the chances of a roll over.”[20] A Shortland Coroner Inquest in New Zealand referred to claims that active riding may increase stability by 10% to 30% [21]. This factor is one reason for not restraining the driver with a seatbelt.

2. Materials and Methods

It is imperative to take preventive action to reduce the thousands of deaths and tens of thousands of injuries associated with ATV overturn hazards. The hierarchy of controls approach offers an opportunity to seek passive controls for preventive action. Thus, the purpose of this study is to conduct an analysis of the prevention effectiveness of a particular CPD, the “Quadbar” (QB), by addressing the question, “How effective is the QB as a CPD in preventing ATV overturn-related injuries?”

The materials used in this study are extant articles and reports. The method used is prevention effectiveness analysis as depicted in the chart shown in Figure 3 [22]. First is determining the plausibility of the QB as a CPD to prevent fatal and/or serious injuries to the rider. Second, applied engineering research is evaluated to determine if the intended intervention of a CPD is efficacious under controlled conditions. Third, extant information is examined regarding whether CPDs and particularly the QB have demonstrated effectiveness under real world conditions. The fourth step, implementation, is a matter of public policy and remains to occur and as a result is not considered in the current study. This is a public health approach to prevention that depends upon direct evidence when available but relies on indirect evidence when necessary [23].

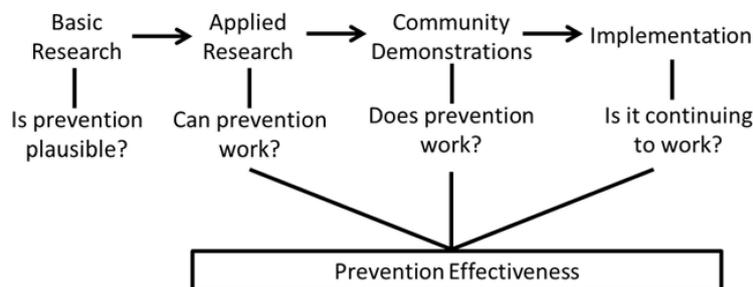


Figure 3. A chart showing the steps and questions addressed in the analysis of prevention effectiveness. Source: Teutsch 1992 [22].

3. Rollovers and Crush Protection Devices: Is Prevention Plausible?

A ROPS has been found to be effective in reducing fatalities associated with tractor overturns by 98% [24]. The success of ROPS on tractors is at the foundation for demonstrating the plausibility of considering passive controls for the protection of life in the event of an ATV overturn.

In 1999, Berry *et al.* presented a paper on research for operator protection on ATVs and side-by-side vehicles [25]. Because a safety frame, roll bar, or ROPS is a proven technology to prevent overturn-related injuries on tractors since the 1960s, Berry and his colleagues designed a ROPS for ATVs as proof that it could be done. The design used four posts and was tested on a hill with a 29° slope in the both the lateral and longitudinal directions. The longitudinal overturn was to the rear, and the machine rolled 360° and back up on its wheels. Tilt table tests were conducted to determine the effect of the ROPS on the stability of the machine. The roll bar reduced the static stability of the unit in the longitudinal direction by 3.5° and in the lateral direction by 2° to 3° [25]. However, the impact on ATV stability of a rider’s weight is significantly greater than that of ROPS [26].

In 2003, researchers at the Monash University in Australia conducted a study of ATV safety and countermeasures. The study found that a philosophy of depending on a rider’s separation from the

vehicle for safety as ill-founded and does not offer protection in the event of overturns or collisions. The study included simulation tests of an ATV with and without a four-post ROPS in which three scenarios were tested. One scenario involved a rollover and two scenarios involved ejections. The rollover without a ROPS resulted in the ATV landing on top of the simulated rider, and the other two without protection resulted in interpretations of severe injuries, one of which was fatal. With a ROPS that included a seatbelt, the occupants would have received minor injuries. Later in 2013, the researchers reflected that the policy should not depend on an “all or nothing” approach at safety, but follow an incremental approach toward occupant protection in order to reduce injuries [27].

In such an approach, a CPD provides space under an overturned vehicle to prevent crush-related injuries to the rider but is not designed with a restraint system. Moreover, in low-energy overturns, a CPD may also arrest the overturn at 90°. In 2012, the Australian government announced the requirement that a CPD be installed on any ATV that was operated by a government employee [28].

A CPD is not designed as protection from secondary crashes (a rider crash after an ATV crash) with a restraint device such as a seat belt. Secondary crashes are problems in collisions and high energy impacts in which riders are thrown from the machine or impact the ground. According to John Lambert, an engineer in Australia, CPD requirements include both safety and operational criteria [29].

- Safety Criteria
 - Be effective in protecting the rider in rear and side overturns
 - Improved safety in front overturns
 - High enough clearance to provide survival space in the upside-down position
 - A safe distance away from the rider to minimize impact with the rider in the event of an overturn
 - Minimize the chance of pinning or spearing a rider in the event of an overturn
- Operational Criteria
 - Should not restrict access and egress from the ATV or driver visibility
 - Have minimal impact on stability with low weight and low center-of-gravity
 - Be low enough to not catch overhead branches

4. Review of Tests of the Quadbar: Can Prevention Work?

This section describes applied engineering efforts to address the efficacy of the QB under controlled conditions. Some efforts examine unanticipated consequences of the QB while other efforts examine its potential and limitations for the prevention of overturn-related fatal and nonfatal injuries.

4.1. Strength Tests

Two tests were conducted regarding the strength of the QB. One test was conducted by Sulman Forensics and Quadbar Industries in 2007 [30], and the other test was conducted by Ridge Solutions in 2009 [31]. Both tests were conducted in lateral, longitudinal, and vertical directions. The former test was conducted according to guidelines from the New Zealand Occupational Safety and Health Service, which met a standard for a mass up to 290 kg (639 lb). The latter test was conducted according to ISO standard 5700-2006, which is used for small tractors that weigh less than 600 kg (1323 lb) that showed that the QB met the standards for a 300 kg (661 lb) ATV. The QB weighs 8.5 kg (18.7 lb) [32].

4.2. Tests by Snook

Snook undertook an assessment of the crush prevention provided by the QB as compared to no CPD in 2009. He used an accelerator slide that could be elevated on an angle and on which the specimen could slide down the elevation creating a velocity against a trip device at the bottom of the accelerator. Tests were conducted on two makes and models of ATVs: a Yamaha Moto 4 250cc and an

ODES Cattleman EX400 series 4x2. Tests were conducted on each unit with side rollovers onto a level ground and onto a 20° sloped ground. More tests were conducted on the Yamaha machine in order to establish consistency of the accelerator performance [7].

Rear overturn tests were also conducted down a 20° slope. These tests were conducted on each machine with and without a QB attached. No front overturn tests were conducted, and no simulated rider such as an anthropomorphic dummy was placed on the seat of the machines. The tests included side rollovers on horizontal and sloping ground and back flips that would typically occur when accelerating up an incline or when braking while rolling backwards down an incline. All tests were conducted under field conditions [7].

According to the tests by Snook, the QB has a potential added benefit of arresting a rollover to the side of the machine and of stopping a complete tip over to the rear and shifting the roll to the side of the machine, averting a complete rollover for low energy tip overs. The Snook tests showed that the QB was effective at providing crush prevention clearance no matter the result in both side and rear overturns, and was effective at causing a machine in rear overturns to yaw to the side away from the rider in the event he or she would fall from the machine [7]. The results of the test are shown in Table 2.

Table 2. Passive crush prevention comparison between no protection and Quadbar protection in field tests using an accelerometer, 2009.

Yamaha Moto 4	Field Slope	No Crush Prevention Device	Crush Prevention	With Quadbar	Crush Prevention*
Side overturn ramp angle 23° and 26°	Level	4 tests at 5.2–6.6 km/h→180° rolls 4 tests at 7.7–8.6 km/h→270° rolls	No No	5 tests at 5.2–8.2 km/h→arrested at 90° 3 tests at 8.2–9.3 km/h→270° rolls	Yes + anti-roll Yes
	20°	1 test at 5.4 km/h→720° roll	No	3 tests at 5.4–5.6 km/h→arrested at 90°; 2 tests at 7.1 km/h→270° 1 test at 10.1 km/h→720°	Yes + anti-roll Yes Yes
Rear overturn ramp angle 24°	20°	1 low speed back flip→180°	No	3 tests at 4.3–4.4 km/h→arrested before 90° yawed to the side and stopped	Yes + anti-roll
ODES Cattleman EX400 4x2	Field slope	No Crush Prevention Device	Crush prevention	With Quadbar	Crush prevention
Side overturn ramp angle 12° & 21.5°	Level			1 test (21.5° ramp angle) at 4.6 km/h→arrested at 90°	Yes + anti-roll
	20°	1 tests (12° ramp angle) at 3.5 km/h→continuous rolls (>90°) 2 tests (21.5° ramp angle) at 4.7 km/h→90° and 180°	No No No	2 tests (12° ramp angle) at 3.5–3.8 km/h→continuous rolls (>90°)	Yes
Rear overturn ramp angle 24°	20°	1 test at 4.1 km/h→continuous roll (>90°)	No	2 tests at 4.2 km/h →arrested before 90° yawed to the side and stopped 4 tests at 4.6–5.2 km/h→continuous roll (>90°)	Yes + anti-roll Yes

*Investigator observed positive crush protection but suggested that the rider would likely fall or be thrown from the seat in violent, high energy, continuous rolls (>90°). No rider simulation was used. Maximum lateral force on the Quadbar was measured in three tests: 2 at 23° ramp angle and 9.2–9.3 km/h velocity with 270° roll, Fmax = 1255 N lateral on level surface; 1 at 26° ramp angle and 10.1 km/h velocity with a 720° roll, Fmax = 1368 N lateral on 20° surface incline Source: Snook 2009 [7].

The Snook tests showed a vast difference in the stability of the two models of ATVs used in the tests once the overturn was initiated. Overturns of one model were arrested by the QB at 90° relative to the surface in the direction of the overturn thus providing an anti-rollover feature, while the heavier

model had continuous rolls once the overturns were initiated. Only in the low velocity rollover did the QB arrest the continuous overturn for the heavier model [7].

Nonetheless, the QB did provide anti-crushing clearance in these rolls, and the assumption was that the rider would be thrown free from the machine during these violent, continuous rolls. In all tests, the QB was effective as an anti-roll device on the Yamaha model whether to the side or to the rear. This study found that differences in vehicle make and model may contribute to their instability and risk of overturn [7].

4.3. The Delta-V Experts Study

Richardson *et al.* of Delta-V Experts in Australia reported the results of a computer simulation study in 2013 [33]. They created an exemplar ATV to simulate forces on ATV riders' body parts using a commercially available collision simulation tool, PC-Crash. They validated ATV rollover tests against data from the Snook study for two ATV configurations: one with and one without a CPD. Snook used the QB as the CPD in his tests. The rollover simulations with unrestrained riders compared four real-world cases (100 simulations for each case and configuration) to evaluate both impact and crush-related injuries to ATV riders. Four fatal real-world cases as follows were simulated:

Case 1: The rider rode parallel to a creek bank then up an embankment. The ATV rolled over trapping the rider's torso. The rider sustained fatal injuries as a result of the rollover.

Case 2: The rider drove the ATV over flat ground to a steep creek bank. The rider applied the brakes to the ATV as it topped over the edge of the bank and rolled down the creek bank. The slope was about 60° with a drop of about 5 m (16.5 ft). The rider sustained fatal trauma to the torso (chest and back).

Case 3: The ATV impacted a 0.5 m (1.6 ft) high ant-hill at about 19 km/h (12 mph) and the rider was ejected from the ATV, and the ATV landed on top of the rider. The ATV rolled 3¼ turns (292°).

Case 4: A 105 kg (231 lb) adult male rode across a side slope on an ATV with a spray tank fitted to the rear frame when the ATV rolled laterally and ejected the rider. The rider was found beneath the ATV. The Coroner identified the cause of death as traumatic asphyxiation.

Based on the simulations of the unprotected ATV and the QB-fitted ATV, the investigators found that the rider could be traumatically or mechanically asphyxiated 32 and 17 times, respectively, with the QB reducing the risk by 53%. The authors concluded that there was an identifiable risk of serious or fatal injury from ATV rollovers, and fitting a CPD to mitigate the potential for injury due to torso impact, crush, or entrapment as a result of an ATV rollover should be considered. Moreover, in all four of the above cases, they concluded that if the ATV had been fitted with a CPD (*i.e.*, QB), the unrestrained rider could have survived the rollover. As with any computer simulation tests, they acknowledged a number of limitations because of the reliance on the data input and assumptions made [33].

4.4. The Quad Bike Performance Project—Crashworthiness

Grzebieta *et al.* launched a project entitled the Quad Bike Performance Project in 2012 with the purpose to improve the safety of ATVs [34]. Since advocates of prevention had suggested CPD use, the initial intent of the project was to test only ATVs, but before testing began, the project was expanded to include the testing of side-by-side vehicles as potentially safer than ATVs. The term used in the tests of CPDs was "operator protection devices" (OPD) that would include the ROPS protections available for side-by-side vehicles [32].

In the Quad Bike Performance Project, tests included overturns in all directions: roll to the side and pitch to the front and to the rear. The tests were conducted with a protocol that compared results of a test without a CPD against tests with a QB attached. A tilt table was used for each crashworthy test with a dummy, an Anthropomorphic Test Device, placed on the ATV without restraint. An instrumented Motorcycle Anthropomorphic Test Device was used to determine injurious response data from the overturn [32].

In the Quad Bike Performance Project rearward pitch test, the QB impacted the ground before the dummy, but this had little effect on softening the dummy impact on the ground, an impact that was common in all tests. Typically, the ATV came to rest on the dummy in the absence of protection of an OPD, but when a QB was present, the ATV came to rest away from the dummy or the QB supported the ATV above the dummy [32]. Table 3 shows the results of the tests.

Table 3. ATV Overturn Test Results without and with Quadbar Prevention in Three Directions That Included an Unrestrained Anthropomorphic Test Device.

Test	No OPD on the ATV	Quadbar (QB) Fitted on the ATV
Lateral	The ATV rolled onto and came to rest on the dummy.	The QB blocked a full ATV rollover (<i>i.e.</i> , anti-roll) onto the dummy as shown in photo ① in Figure 4.
Rear Pitch	The ATV pitched rearward onto the dummy, pitched up, and pivoted about the front, lifting the rear of the ATV into the air, which landed on the dummy a second time and onto the dummy’s leg.	The QB restricted an ATV pitch over. The ATV came to rest on its rear with the dummy lying on top of the QB. The top section of the QB was bent from the test.
Forward Pitch	The ATV pitched onto and came to rest on top of the dummy as shown in photo ③ in Figure 4.	The ATV pitched forward until the QB contacted the ground and came to rest upside down above the dummy with the rear of the ATV supported by the QB and minimal load on the dummy as shown in photo ② in Figure 4.

Source: Grzebieta *et al.* 2015 [32].

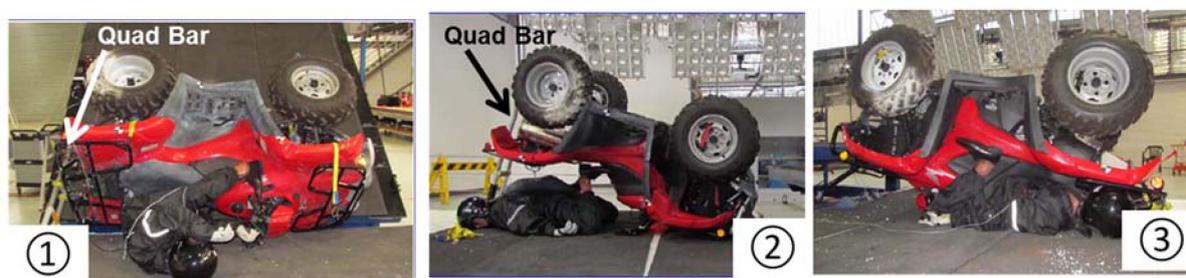


Figure 4. Tests that show ① crush protection provided when the Quadbar serves as an anti-roll bar in a side overturn, ② the clearance provided by a Quadbar for the dummy in a forward overturn, and ③ a dummy crushed in a forward overturn without a CPB. Source: Grzebieta *et al.* 2015 [32].

Researchers concluded that in static stability and dynamic handling tests the QB was not detrimental to the ATV stability or handling. They also concluded that OPDs may be beneficial in low speed environments, but OPDs may prove hazardous in some crash circumstances but has yet to be shown in real world cases [35]. The investigators considered that an OPD would likely result in a net benefit in terms of reducing harm to workplace ATV riders involved in an overturn [27]. Indeed, the QB provides survival space in the event of an overturn and provides protection against crushing injuries and especially against chest compression asphyxia. It can also serve as an anti-roll bar to stop an upside down overturn to the side or to the rear.

4.5. Tests of the Net Effect of the Quadbar

While innovators have suggested different types of machine-based protections for riders, in Australia the ATV manufacturing industry has claimed that the QB increases the danger of impact injuries in the event of a crash in addition to crush-related injuries (*i.e.*, the net effect). Some simulation tests support this claim [36].

In a 2012 report, Monash University conducted a review of the literature regarding research on the efficacy of the QB. This review identified major deficiencies in research methods in some industry funded tests as follows [37]:

- No computer simulations of crashes of QB-equipped ATVs could predict asphyxiations, which account for 40% of ATV overturn-related deaths in Australia.
- Computer simulations contained insufficient information to define incident scenarios.
- Assumptions and interpretations significantly altered the simulation results.
- Potential inaccuracies were apparent in modeling terrains, selection of ground stiffness and friction coefficients, and common use of extreme lengths of slopes.
- There were unexplained shifts in over-predicting head injuries while “virtually” eliminating chest injuries.
- Susceptibility of an International Standards Organization method for calculating benefit ratios involved extreme selection bias in the use of test scenarios, inherent variability in individual cases, and comparisons of minor injuries to fatalities.

In response to this evaluation, investigators conducted dynamic field tests that were reported in 2015 [38]. The results of these tests are yet to be evaluated by other investigators or peer reviewers.

5. Effectiveness: Does Prevention Work?

In answering the question, “Does prevention work?” in the real world, no planned community trials have been conducted. Evidence is based on interpretations of extant statistics and anecdotes. Nonetheless, a natural experiment is underway: Lower at the Australian Centre for Agriculture Health and Safety in New South Wales reported in August 2015 on a review of ATVs in New Zealand and Australia over a 15-year period since 2000. The review found that at least 10,000 ATVs have some form of CPD, and they were unable to find a single incident where the CPD was implicated in a fatal overturn [39].

In a 2008 study conducted in New Zealand, Moore observed that 20% ($n = 31$) of quad bikes had roll bars fitted to the machines [40]. At a 2015 Inquest by Coroner Lord in Australia, Lower estimated that the total CPDs in place in New Zealand was 8,000 units, which represented 10% of the machines there [41].

Moreover, David Robertson, inventor of the QB, reports that he has sold more than 3700 QBs since 2007, mostly in Australia. He reported that more than 100 QBs had been fitted on ATVs at a resort where more than 3000 tourists ride QB-equipped ATVs per month. The Director at that resort reported that since fitting the ATVs with QBs, injury rates declined by about 90%. Furthermore, Robertson said no deaths have been identified with the use of CPDs in New Zealand and Australia [13].

In a 2015 Inquest in Australia, Coroner Freund found that it was clear for some fatalities that a CPD may have been effective at preventing deaths from an ATV overturn. In two of the nine deaths investigated (22%), the CPD may well have saved the decedent’s lives. However, caution was raised regarding potential CPD adverse effects of a rider unable to separate from an overturning ATV or not rolling off of the victim [13].

Helmkamp referred to Australian research at the 2012 CPSC ATV Safety Summit and suggested that fitting ATVs with QBs could potentially reduce the number of ATV-related deaths by up to 40% [42]. Helmkamp’s reference was likely conservatively based on Australian engineer and technical expert predictions of a reduction by 40% to 50% of both fatalities and serious injuries when a QB was in place on an ATV [29].

Lambert in a Public Discussion Paper about quad bike safety opined that the QB is an ideal start for reducing deaths and serious injuries by 80% [29]. In 2015, he also stated that at least 20 individuals claimed that their lives were saved as a result of the QB [43]. Lambert conducted a 2015 analysis of the effectiveness of the QB against a status quo baseline without protection. Regarding ATV-related fatalities, the typical rate was 0.85 deaths per 10,000 ATVs; his early estimate was a reduction with

the QB to 0.51 deaths per 10,000 ATVs. However, to date, no deaths have been associated with a QB-fitted ATV, for that matter any CPD-equipped ATV. He assumed 40 hospital admissions per 10,000 ATVs for the status quo and predicted 24 cases per 10,000 ATVs with the QB fitted ATVs. He observed only 2 cases of admissions for an equivalent of 10,330 ATV-years as of 2015. These figures were in sharp contrast and disproving of the Federal Chamber of Automotive Industries in Australia prediction that QBs would increase deaths by 5.83 times and injuries by 3.96 times based upon computer simulations [44].

Anderson testified at the Lock Inquest in 2015 that he had extracted data from a computer simulation report by Dynamic Research Inc. He reported at the Inquest, a non-statistically significant net benefit of the QB at 12% [45]. However, Anderson expressed some caveats regarding his interpretation of the results. The benefits of the QB focused on head, neck and lower extremities but not for the thorax and abdomen, where benefits would be expected. Indeed, the computer simulation predicted “relatively few thoracic injuries” whereas head and neck injuries dominated the high severity injuries. He testified that this disparity was inconsistent with results in a Clapperton *et al.* article in which ATV-related severe injuries were equally represented between the thorax and the head [8]. Anderson’s testimony was based upon all incidents (net effect), whereas the Lambert opinion was based on an overturn incidents subset. In Sweden, an analysis group’s calculations indicated that a ROPS on ATVs has the potential to reduce the number of road fatalities by up to 70 per cent, while admitting that more research is needed [3].

6. Discussion

The QB was found to be effective as a CPD for potentially preventing overturn-related injuries. These injuries include the prominent problem of the asphyxiation of victims by keeping the weight of the machine off of the victim. In the physical tests that were reviewed, it was apparent that the QB provided survival space under an overturned machine, no matter the direction of the overturn. A side benefit beyond the design purpose of the QB is its feature of stopping an overturn (*i.e.*, anti-roll bar) in low-energy events and to divert rear overturns to the side away from the rider. The QB design is consistent with the criteria laid down by Lambert for CPDs, and the actual field experience of nearly 4000 QBs in use over multiple years has resulted in no known deaths or serious injuries related to overturns. Indeed, testimonials claim that the QB prevented serious injury or death in overturns.

Nonetheless, the Freund Coroner’s Inquest in Australia found in 2015 that SafeWork NSW, Safework Australia, and CPD manufacturers, QB and “Lifeguard,” should collaborate in an independent survey to assess the benefits, risks, and general efficacy of CPDs [13].

In fact, systematic “real world” studies are needed to compare overturn incidents of ATVs with and without a CPD. One opportunity is a possible retrospective study of the reported 90% reduction in injuries at a resort in Australia after 100 ATVs were fitted with QBs as reported by Robertson [13]. Richardson *et al.* suggested that more detailed incident investigations are needed [33]. An investigation tool, the Haddon Matrix [46], provides a tool for such investigations, which the US National Institute for Occupational Safety and Health uses in its Fatality Assessment and Control Evaluation Program [47].

There is a social cost of delay in solving the problem of hundreds of deaths and tens of thousands of injuries associated with ATV incidents annually. The longer the delay in action, the more lives and livelihoods are affected. If the weight of the machine dropping onto a human body in ATV overturns can be held at bay, lives can be saved and crush-related injuries can be averted. The CPD is designed for this purpose, and the QB appears to be a reliable device to accomplish this purpose.

7. Conclusions

ATV overturns cause hundreds of deaths and tens of thousands of injuries per year, a tragic and unintended consequence of these machines entering the market. A major reason for these deaths and injuries is ATV overturns that crush or asphyxiate the rider. The QB is potentially effective at averting these deaths and serious injuries. It provides crush protection clearance for the rider in an overturned

ATV, especially in low energy overturns. Moreover, in a side rollover, the QB acts as an anti-roll bar stopping a continuous roll, and in rear tip overs, it likely diverts the machine to the side away from the rider. Fitting the QB or other CPDs to ATVs appear to have a potential for reducing serious or fatal injuries in the event of ATV overturns. A systematic study is needed of the effectiveness of the QB in actual use, and serious consideration is needed regarding fitting CPDs as standard equipment on ATVs.

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