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# All-Terrain Vehicle-related crashes among children and young adults: *A systematic review of the literature with illustrative case report*

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**Abstract:** All-terrain vehicle (ATV) by its design, represent a highly dangerous mode of transportation. Pediatric ATV crashes were at least 30 times more likely than four-wheeled vehicles crashes and almost 20 times more likely than motorcycle crashes. ATV riders are highly vulnerable road participants who are exposed to severe, often multiple injuries. Relative to automobiles, ATVs, due to their imperfections, pose a greater hazard of death or serious injury to operators and passengers. The most common mechanism of crashes is rollover, hitting a stationary object followed by hitting a moving vehicle. While lower extremity injuries most commonly occur in ATV-related crashes, head injuries are most frequent in fatal crashes. The operators who are killed often are children and young adults, too young to legally operate all-terrain vehicles. The aim of this paper is to highlight some of the medico-legally important aspects of fatal and survived ATV crashes illustrated by an analysis of a case involving an ATV. Although ATVs-associated morbidity and mortality is increasing problem among children, extensive literature search failed to find a comprehensive, medico-legal review of the ATV-related crashes.

**Key Words:** ATV crash, ATV-related injuries, children, medico-legal evaluation.

**Methods**.
A comprehensive, computerized literature search of Medline was first conducted. The medical subject headings, ATV injuries and children, identified approximately 90 papers published from January 1992 to October 2012. Subsequently, medico-legally-related papers were selected. A number of technical reports and the articles from references of the abovementioned papers, which could not be identified from Medline, were also added to this review. Moreover, an illustrative case study of ATV-related death of young adolescent is analyzed in this paper.

**Introduction and epidemiology**

The expanding ATV use in modern society is reflected in the practice of forensic medicine. ATVs were originally designed in the early 1970s for occupational use in the agricultural and forestry industries as economical alternatives to the tractors and trucks [1,2].

Since then, the popularity and use of ATVs has increased in recent years [3]. Therefore, mortality and morbidity have concurrently expanded. For example, in West Virginia, ATV - related deaths rate doubled between 1999 and 2006 [4]. Medical Examiner reports, from the same state, were completed on 112 victims who died in ATV crashes from 1999-2004: 7% were riding as passengers at the time of the fatal crash; 15% were wearing helmets with 35% of these victims sustaining a head injury; almost 3/4 of the victims were not wearing a helmet and 56% received head injuries. Blood alcohol levels were positive in nearly half of all decedents with about 73% of those aged 21 to 34 testing positive [5].

In New Zealand, one third of accidental child fatalities on farms involve ATVs [6]. In Pennsylvania ATV

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related fatality rates increased by 95% between 1993 and 2002 [7]. This multipurpose vehicle has also increased in recreational use by children and young adults in recent years. ATV use by youths under 16 years old is increasing [8,9]. A more in - depth analysis of the US data indicates that from 1999 to 2009, 2 674 (26 % of the 10,281 total) ATVs - related deaths of children younger than 16 years old were reported, where 1 140 (11 % of the total number of fatalities) were younger than 12 years of age [10].

In the US, more children die each year from ATV-related events than from bicycle crashes [11]. The fatality rate for males is nearly 7 times greater than for females [5]. According to Blecker et al. ATV-related crashes were at least 30 times more likely than motor vehicle crashes and almost 20 times more likely than motorcycle-related crashes [12]. Moreover, ATV riders are more severely injured than motorcycle riders [13]. That is why the concerns about the safety of ATVs have risen in the last time. Total pediatric hospitalizations for ATV injuries in the US have increased 150% from an estimated 1,618 in 1997 to 4,039 in 2006; the overall ATV-related injury hospitalization rate increased 139% from 2.3 per 100,000 in 1997 to 5.5 per 100,000 in 2006 [14]. It is presumable these trends will be similar in Central and Eastern Europe and ATV accidents will also become an integral part of the forensic practice in this region.

**Brief technical background**

ATVs are unstable, unsafe and unregulated vehicles capable of speeds in excess of 100 km/h [15]. This heavy, 4 - wheeled motorized vehicles with motorcycle – like engines and handlebars have a high centre of gravity and large, low - pressure tires predominantly designed for unpaved terrain use [16]. ATVs range in engine size from 50 cm3 to more than 600 cm3 of displacement and can weigh as much as 200 kg. Bernard et al. examined pediatric anthropometric fit criteria (handlebar-knee distance; hand size; brake-foot position; standing-seat clearance and elbow angle) for young riders on adult and youth-sized ATVs; he found out that children aged 12-15 years fit the adult-sized ATV better than the ATV Safety Institute recommended age-appropriate youth model (63% of subjects fit all 5 measures on adult-sized ATV vs. 20% on youth-sized ATV); youths aged 6-11 years fit poorly on ATVs of both sizes (0% fit all 5 parameters on the adult-sized ATV vs 12% on the youth-sized ATV) [17].

Individuals of lighter weight and smaller arm span, such as those in the pediatric population, are under considerable risk of injury when operating an ATV due to lateral, longitudinal, and vertical operational instability [18]. ATVs are typically built for one operator because of proper weight distribution and maneuverability; however half of all ATVs operators carry one or more passengers [19]. Children are often injured when they are thrown from a ATV while riding as passengers [20].

An ATV passenger is not in an advantageous position to exercise any control over the operator in the operation of the ATV (no control at all over the speed, steering, or braking). Passenger visibility in the front is poor, unlike that of a front seat passenger in a car. ATV passive safety-devices such as airbags, rollover protection structures (ROPS) and safety restrains in the event of a crash or collision are typically not present. The effectiveness of the ROPS within the literature is limited and disputed. In other hand, wearing a helmet reduces the risk of death and prevent brain injury [21,22,23].

However, no protective device can reduce all possible injuries.

**Mechanism of injury and selected biomechanical principles**

Motorcycle and ATV- related accidents are based on the laws of Newtonian physics [24]. Newton´s First Law states that a body in motion remains in motion unless acted upon by some outside force and a body at rest remains at rest unless acted upon by some outside force. This means that the vehicle will continue at a given speed and direction unless the operator breaks, accelerates, turns, or crashes into another object. Most ATV - related injuries occur after the operator or passenger gets ejected from the saddle. Newton´s Second Law states that force equals mass time acceleration. When two vehicles collide, each vehicle experiences a sudden change in speed called acceleration (deceleration). This change in speed is known as Delta-V.

Consequently, delta-V is generally a suitable measure of the force of the collision. Since force is what injures riders, delta-V is useful for quantification of injury severity. Newton´s Third Law states that every action has an equal and opposite reaction. In any traffic accident, the force that the vehicle applies to the object is equally opposed by the object. Since the rider is not attached to the ATV, after an impact with a larger object, the rider or passenger is usually ejected from the ATV (Newton´s First Law). Upon impact with a massive object, the rider will experience a sudden deceleration as his or her body slows down to match the velocity of the object he or she has impacted. Taking into account of Moroney et al. the most common mechanism of injury by ATV is rollover while driving up or down steep gradients [15].

Moreover, children have a significantly greater risk compared with adults of right-side rollovers on flat and uneven surfaces [25]. The second most common mechanism is lost of control of the vehicle with a consequent collision with a stationary object (roadside trees, poles, guardrails, etc.) or being thrown from the vehicle. The third most common group fell due to rough terrain or to collide with other ATVs [15].

**Patterns and severity of ATV injuries**

AATV occupants often sustain multiple injuries in a collision. Injuries to children and youths in ATV-related crashes typically include orthopedic, craniocerebral, spinal and soft tissue high-energy mechanical trauma. Craniocerebral injuries being the leading cause of significant morbidity and mortality, particular in single ATV crashes and head-on collisions [19,26-32]. During the period of 3 years, 70 ATV deaths were identified in the 2 U.S. states; the primary cause of death for children in ATV crashes was head and neck injuries followed by thoracoabdominal injuries, extremity and vascular injuries, asphyxiation and multiple trauma [29].

The head is very vulnerable to injury, often with severe consequences. It is particular susceptible to acceleration/deceleration and rotational kinetics. As the fixed and non-fixed parts of the body such as craniocervical segment move differentially, deceleration injuries such as multifocal vascular trauma, or diffuse axonal injury may occur [33]. Among ATV occupants the most common fatal head injuries comprise brain contusions or hemorrhage, followed by subdural hemorrhage, subarachnoid hemorrhage and skull fractures. Helmets reduce head injuries but did not offer protection for the spine; ATV-related spine injuries are different from other ATV-related injuries in children in that they are more common in older children and in females [34].

The most common segment of fracture is thoracic followed by lumbar and cervical [35]. Maxillofacial and ocular injury patterns from ATV-related crashes in children have been reported in several studies [36-40]. Facial soft tissue injuries are highly prevalent, regardless of riders/passenger position on the vehicle or mechanism of accident. Maxillary and nasal/orbital fractures are most common, while mandibular fractures are highly associated with non-penetrating head injuries [37]. ATV-related ocular injuries range in severity from subconjunctival hemorrhages, periorbital ecchymoses to orbital fractures and traumatic avulsion of the optic nerves [36,38]. Graham et al. reported unique and severe ATV-related "cloth-line injuries" of the neck and face of children and adolescents; severe neck and/or facial lacerations was caused by striking a wire fence or clothesline while riding an ATV [41]. Penetrating injuries of lower extremities by wooden sticks followed by ATV crash has been published recently, moreover,

Long published uncommon case of cranial impalement of an 8-year-old child by ATVs brake handle [42,43]. The most common injury observed in young ATV riders are fractures [26,44]. Fracture sites in young ATV riders also appear to vary with age category: older youths were more likely to sustain pelvic fractures while younger ones were more likely to sustain lower extremity fracture [45,46]. Regardless the most frequent types of ATV-related injuries comprise head and extremities, ATV crash can lead to life-threatening abdominal injuries. Several studies identified and discuss the mechanistic risk factors associated with genitourinary trauma (predominantly renal) in pediatric all-terrain vehicle (ATV) accidents [47,48]. Pelletier et al. evaluated 435 patients with ATV-related injuries, with an overall mortality of 4.6%; 55% of patients were not wearing helmets, with most of the deaths (85%) occurring among these individuals; children accounted for 18.9% of all patients and 15% of deaths [49].

The study of Shah et al. included 512 consecutive children suffering from ATV injuries; head injuries occurred in 244 children (48%); cranial vault fractures occurred in 104 children and were associated with brain, subdural and epidural injuries; brain and orbit injuries were associated with long-term disability; total of 227 extremity fractures were present in 172 children (34%); the femur was the most commonly fractured bone; nine children had partial foot amputations; multiorgan injuries occurred in nearly half of the 97 children with torso injuries; determinants for long-term disability or death were head injuries and extremity fractures [50].

A retrospective study was undertaken of 643 cases of children less than 16 years old hospitalized between 2000-2006 due to possible ATV-related injury; there were 218 confirmed cases of ATV injury; the majority of injuries were orthopedic, soft tissue injuries and head injuries; multiple injuries occurred in 74 cases; six children were left with a permanent disability and sixteen children died [51]. Because crash mechanisms and injury types are functions of rider age and other factors, the dynamics of youth ATV accidents is likely complex but possibly predictable [17].

**Short case report**

Initial Background Information and concise autopsy findings: An ATV operated by adult male went out of control on the road curve and hit head on bus stop pole. A passenger, 16-year-old, non-helmeted adolescent, was ejected from the saddle and subsequently thrown against nearby solid concrete stairs. A moderate amount of blood was on the pavement beside the body.

Cardiopulmonary resuscitation was unsuccessful and she was pronounced dead at the scene. The autopsy confirmed multiple fractures of the vault and base of the skull, confluent subarachnoid hemorrhage, severe brain edema and lacerations of brainstem and cerebellum. Internal examination of the thoracic cavity revealed fracture of the thoracic and cervical spine with atlanto-occipital transsection. The blood and urine tests for alcohol concentrations showed zero levels. Other toxicological investigations, employing routine methods, of the blood and urine were negative.

Summary and opinion: Based on the circumstances surrounding death and on the autopsy

**Table 1.** Modified Haddon´s matrix for ATV-related risk factors

| Phase | Human factors | Vehicular factors | Environmental factors |
|---|---|---|---|
| **Pre-event** | Male gender, young age, alcohol and drug impairment, crash history, excessive speed, no driver´s licence, traffic violation history, immature judgment, inexperience, high risk-taking behavior, lighter weight and smaller arm span | rider-ATV misfit, high-powered, large-displacement engine | Nighttime, rural area, up or down steep gradients, unpaved terrain |
| **Event-crash** | Absence of protection devices (e.g. helmet, hit-air airbag safety jacket motorcycle protective gear), excessive speed, riding as a passenger | Absence of protection devices (e.g. ROPS, hand guars, safety restrains) | Collision with solid stationary objects (trees, roadside barriers) |
| **Post-event** | Pre-existing disease | | Insufficient emergency and hospital preparedness |

findings, required the conclusion that adolescent died from a multiple skull fractures and lacerations of brainstem due to blunt impact to head. Therefore, the manner of death was accidental.

## Conclusion

Driving an ATV appears to be a hazardous activity which can result in a fatal outcome [4,22,25,45]. The popularity of these vehicles has increased among both children and adults. There is no question that experience plays an important part in ATV safety. The literature has identified a number of risk factors, including engine size, rider-ATV misfit, younger child age, alcohol impairment and failure to wear helmet [16,17,22,52]. Another risk factor is high weight and excessive speed which demand high degree of coordination, muscle strength, mature judgment and experience for safe operation [7].

As shown in Table 1, risk factors for ATV-related injuries are categorized according to the modified Haddon matrix. The Haddon matrix consists of three phases of a crash event, along with human, vehicular and environmental factors. The presence of just one passenger - whether situated behind the driver or in front of him impairs the safe operation of the ATV [53]. To safety control the ATV the driver must have the ability to make quick body shifts combined with acceleration and breaking. Reliable information regarding the European incidence of ATV crashes is lacking because no uniform reporting system exists for ATV incidents. Responsible operation of an ATV depends upon many factors which include training, experience, supervision, developmental stage and vehicle condition. In cases of fatal ATV accidents close interaction between police and forensic pathologists is essential, because autopsy findings may be misleading in the absence of satisfactory accident scene information. Public education and awareness of the hazards associated with ATV use need to be targeted toward both parents and children likely to use ATV.

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