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# Non-Fatal Injuries Associated with Riding Roller Coaster

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## Abstract

The deaths related to riding roller coaster are insignificant, but there are multiple reports about non-fatal injuries like neurological, cardiovascular, urological, ophthalmological and connective tissue injuries. The most common lesions reported in the literature associated with riding roller coaster are cardiac and brain damage. We conducted a literature review from 1995 to 2017 using the keywords roller coaster and neurological/vascular injuries. We found 21 articles related to neurological injuries and 13 for vascular injuries it was important for the selection that articles clearly describe neurological o vascular clinical cases and the association with riding a roller coaster. Finally, we work only with 9 articles for neurological and 6 for vascular injuries. Some of the cases presented in this review were correlated to pre-existing trauma or aneurysms. With this review is clear that the risk of injury by riding a roller coaster is low, but emergency physicians should know that amusement park rides could be related to inexplicable symptoms associated with extreme conditions in the roller coaster rides.

**Keywords:** Roller coaster; Neurological injury; Vascular injury

## Introduction

The country with the larger number of roller coaster is the United States and there is no real control over the accidents related to riding a roller coaster, it is mentioned that in 2003 the US consumer Product Safety commission (CPSC) estimates that 6900 non-occupational injuries attended in emergency occurred on amusement rides [1]. The number of deaths related to riding a roller coaster is insignificant 4 deaths annually, compared with the nearly 300 million people each year, but it is very important to take into account that there are multiple reports about non-fatal injuries like neurological, cardiovascular, urological, ophthalmological and connective tissue injuries associated with riding roller coaster [2].

During riding roller coaster passengers are submitted to a high speed, sharp curves and vertical and horizontal gravitational force (G force), a directionless quantity of linear acceleration, which are usually dangerous for passengers, as they cause changes in blood pressure and moving the blood toward the feet or the head, these sudden acceleration changes have been associated to risk of damage in different organs or systems.

Whitcomb et al., recognized that cardiac and brain damage as the most common causes of death following the roller coaster rides [3]. The most powerful roller coasters are 4-6 G forces, studies in pilots shows that 5-9 G forces are the maximum limit for humans, but it is simplistic to do the analysis based only on the G force without taking into account other factors such as time, roller coaster applies brief accelerations in different directions throughout the ride [4]. The injuries in the roller coasters are produced not only by the acceleration (G force) also the velocity and ride time.

A series of medical case reports have described a potential causal relationship between injuries and riding 'high G force' roller coasters [5,6].

Concerning to brain injury and roller coaster two independent scientific panels and an engineering consulting firm failed to find a connection [7,8].

An important limitation in assessing the cause of injury during riding roller coaster is the unknown presence of pre-existing conditions that could augment a person's susceptibility to injury. There are also reports that suggest that the neurological injury is most common among elderly persons or in those with malformations or anticoagulant medication.

## Literature Review

A literature search was conducted from 1995 to 2017 using the keywords roller coaster and neurological/vascular injuries. A combination of these keywords was used in subject headings including the advanced search criteria, with the filter of years, case reports in humans and full text articles.

Articles were acknowledged *via* extensive electronic searches of the standardized computer data base PubMed and Medline.

The main goal was to identify case reports and relevant studies describing injuries which clearly describe the relation to the roller coaster ride.

 

The search of the data bases yielded 21 articles of Neurological injuries and 13 of vascular injuries (**Figure 1**). 9 articles of neurological injuries and 6 of vascular injuries were retained for full review. We eliminate studies if the case was not well described or if the case was not clearly correlated to the rollers coaster ride.

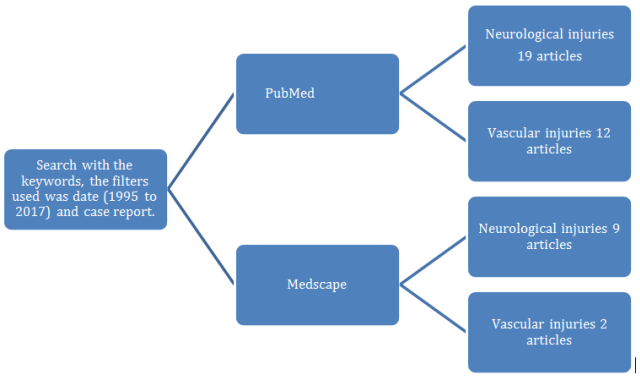


**Figure 1** The number of articles that the different pages retrieve.

Excluded for the following reasons:

1. They were not case reports.

2. The relationship with the roller coaster and the ride was not clear.

3. The information was not complete.

# Results and Discussion

## Neurological injuries

Neurological injuries associated with Roller coaster are very infrequent [9] nevertheless; they represent a high percentage among the roller coaster associated injuries.

Neurological injury is a term to encompass a big group of injuries. Nevertheless, they differ in signs and symptoms, thus the treatment must be accurate for the injury.

Most authors reported that the symptoms associated with these injuries are commonly presented days after the ride, but there are also reports of cases in which the symptoms are present immediately after the ride, the most common symptom is pain.

Some authors have reported neurological injuries in patients that have been on a roller coaster with 3.5 G (meaning the acceleration of the roller coaster was 3.5 times the gravity acceleration) [10], which is relatively low in comparison with other roller coasters.

On the next table, we resumed some cases with neurological or ophthalmological injuries after a roller coaster ride reported in medical literature (**Table 1**).

The ophthalmic injuries presented symptoms immediately after the ride and most of the neurologic injuries which start their symptoms time after the ride.

**Table 1** An abstract of the articles selected associated with roller coasters and neurological and ophthalmological injuries.

| Pathology | Clinical manifestations | Antecedents | Symptoms onset | Age/Sex | Outcome | Author and year |
|---|---|---|---|---|---|---|
| Bilateral multiple retinal hemorrhages | Complaint of dark spot" on vision. | Active smoking and use of oral contraceptives | Immediately | 22/W | Full recovery | Patel, 2015 [11] |
| Macular hemorrhages | Patient referred "wavy spot". | Oral contraceptives | One day after | 26/W | Full recovery | Asefzadeh, 2009 [12] |
| Silent Sinus syndrome | Vertical diplopia. | Non-relevant | Immediately | 39/M | Full recovery | Singman, 2014 [13] |
| Retinal detachment | Loss of inferior visual field in her left eye; Myopic degenerative changes with several areas of lattice degeneration in the retinal periphery. | Non-relevant | Hours | 54/W | -- | Shaikh, 2011 [14] |
| | Floaters and non-specific visual changes. Atrophic holes, lattice degeneration, and a myopic fundus in both eyes. | Non-relevant | Unknown | 35/W | -- | |
| Barotrauma | Otalgia and sensation of fullness. Right external auditory canal was edematous, erythematous, and the right tympanic membrane was injected. | Non-relevant | Approximately 36 hours after roller coaster | 24/M | Full recovery/ Symptoms resolved with 72 hours. | Al-Khudari, 2011 [15] |

| | | | | | | |
|---|---|---|---|---|---|---|
| Cervicocephalic arterial dissection | Headache, vertigo, constant nausea and ambulatory dysfunction, ataxia, dysmetria and vertical nystagmus. | Non-relevant | 2 weeks after | 22/M | - | Leitao, 2012 [16] |
| Acute Parkinson syndrome after ventriculoperitoneal shunt malfunction | Lethargic, generally rigid, unsteady and limb tremor. | Pineal gland germinoma (14-years-old) | Next day after the roller coaster drowsy; 2 weeks after: lethargic, stiffness, unsteady and limb tremor | 17/M | Full recovery | Lau, 2011 [17] |
| Ventriculoperitoneal shunt malfunction | Headache, vomiting and lethargy | Hydrocephalus secondary to premature birth | Immediately | 12/M | Full recovery | Gegg, 2009 [18] |
| Subdural hematoma | Headache | Hypertension controlled with triamterene and hydrochlorothiazide. | Immediately | 64/M | Full recovery | Bo-Abbas, 1995 [19] |
| Glaucoma | Blurred vision and floaters in left eye. | Marfan's syndrome and right ntracapsular cataract extraction. | Immediately | 32/M | Symptoms improved | Andrews, 1994 [10] |
| Posttraumatic migraine | Severe headache, sleep problems, memory problems, irritability, blurred vision, vomiting and nausea (bilateral throbbing pain followed by visual blurring, nausea, and vomiting 2 months after). | Non-relevant | Immediately | 28/W | | McBeath, 2000 [20] |

The average age of the cases reported in **Table 1** was 31, 25-years-old. We analyzed if the gender was important in these types of injuries and we didn´t find it relevant (41.66% women *vs.* 58.33% men).

## Vascular injuries

The vascular injuries are associated with the acceleration and deceleration movements. Shearing tissues can be an effect of moving a steady part from a fickle one.

In relation to pulmonary circulation, the main problem associated with roller coaster is the sudden pressure changes that can affect capillary circulation, resulting in ventilation problems and capillary endothelial disruption.

In the **Table 2**, we resumed the cardiovascular and pulmonary traumas share one fact in common: The onset of the symptoms is immediately after the roller coaster and the symptom and the most common is the pain, generally acute pain.

## Physiopathology of the injuries

**Ventriculoperitoneal shunt malfunction:** We review two case reports of ventriculoperitoneal shunt malfunctions due to a proximal catheter blockage related to roller coasters. In both cases the shunt was occluded by normal tissue, coinciding with the report of other authors [11-27]. In one case, the proximal catheter was occluded by a blood clot [18] and the other one, was occluded by normal brain tissue [17]. Bates et al., reported that half of all shunt malfunctions within the first 2 years are associated with proximal catheter blockage [27].

Browd et al., described that choroid plexus ingrowth may obstruct the proximal catheter and surgical removal is complicated due to the risk of bleeding by the avulsion of the choroid plexus [28]. In the first case, the G force in the roller coaster ride could induce movement of the proximal catheter avulsed the choroid plexus starting a coagulation process and the blood clot occluded the proximal catheter leading to a shunt malfunction.

In the second case, the article describes that the patient repeated several times the ride and these could produce a movement of the proximal catheter encrusted into the choroid plexus causing a blockage on the proximal catheter. This case differs from the first case in order that the obstruction was caused by normal brain tissue and not by a clot caused by the avulsion.

**Barotrauma:** Barotraumas are classified in three types: Alternobaric, atmospheric and Inner Ear Decompression Sickness (IEDS) [15]. The case reported by Al-khudari was classified as an atmospheric barotrauma, which is characterized with extremes of pressure or abrupt changes in the middle ear pressure. In the case, the author shows that the pressure needed to cause an atmospheric barotrauma is 25 pounds/inch and the patient was only submitted to 0.6 pounds/inch. The pressure was not enough to injure the tympanic membrane but was enough to collapse the capillary network of the external auditory canal triggering an inflammatory process [15].

**Table 2** An abstract of the articles selected associated with roller coasters and vascular injuries.

| Pathology | Clinical manifestations | Antecedents | Symptoms onset | Age/Sex | Outcome | Author and year |
|---|---|---|---|---|---|---|
| Aortic dissection | Acute chest pain | Hypertension<br>Diabetes mellitus<br>Chronic renal disease | Immediately | 34/M | Full recovery after 12 days | Springer, 2013 [21] |
| Bilateral internal carotid artery and vertebral artery dissections with retinal artery occlusion | Right-sided neck pain Frontal headache Loss of vision in her right eye Retinal edema | -- | Immediately (neck pain)<br>Five days later (ophthalmologist symptoms) | 35/W | Full recovery | Ozkan, 2011 [22] |
| Pulmonary hemorrhage | Acute chest pain<br>Acute hemoptysis (150 ml)<br>Palpitations and dyspnea<br>Tachycardia, tachypnea, hypertension and mild hypoxia | -- | During the ride descent (chest pain) | 40/W | Full recovery | Yin, 2011 [23] |
| Pneumothorax | Sharp chest pain Dyspnea | Healthy | Immediately | 16/M | Full recovery | Thakur, 2005 [24] |
| Bilateral vertebral artery dissection | Vertigo Left-sided neck pain Blurred vision in her right eye | -- | After many roller coaster rides, Spring 2005 (vertigo)<br>October 2005 (neck pain)<br>2 weeks later since October (blurred vision) | 34/W | Full recovery | Schneck, 2008 [25] |
| Traumatic bilateral extra cranial carotid artery aneurysms injury | Left eye pain Headache Left temporoparietal numbness | Horner´s syndrome<br>Petrous cholesterol granuloma<br>Subtle parietal and occipital neuronal loss bilaterally | 3 weeks before seeing his doctor | 39/M | Full recovery | Stahlfeld, 2002 [26] |

The macular hemorrhage was associated also with a barotrauma, in the article is mentioned that during the roller coaster ride, the patients experiences an increase on the pressure on their face. This increase in the pressure is also exerted to the eyeball. The anterior and posterior chambers of the eyeball are pushed to the retina and choroid layer. The pressure exerted to the choroid layer injures the capillary bed provoking a macular hemorrhage.

**Glaucoma:** Chan et al., reported in 2017 that glaucoma an etiology was not fully characterized [29]. The traumatism caused by the acceleration of the roller coaster propitiates an anterior dislocation of the crystalline and vitreous humor. This way, the trabecular mesh-work got occluded and started a pathologic process of open angle secondary glaucoma.

**Pneumothorax:** Pneumothorax in young patients has described like a valve phenomenon, generally associated with sudden pressure changes. The abruptly descents in roller coaster makes an abruptly inside of air to the pulmonary parenchyma, this causes an elevation of the intra-alveolar pressure and a laceration of the visceral pleura. The air inside cannot get out from the pleural cavity and this is resulting in an elevation of the intrathoracic pressure.

**Pulmonary hemorrhage:** During the "up-and-down, to-and-fro" movements in roller coaster, it produces a tensile and shearing tissue. One of the mainly tissues damage is the capillary endothelium causing microhemorrhages. The principal mechanism is a transient increase pulmonary capillary pressure. Multiple microhemorrhages its clinical seen like acute hemoptysis.

## Conclusion

Roller coaster rides have been associated different injuries related to acceleration, G forces, rotations and turn; it is important to consider that modern roller coasters are getting faster and furious and can reach as high as 6 Gs, these could increase the injuries associated to the roller coaster. To know the risk for humans in roller coaster is necessary to know many parameters not only G force, it is important to take into account the Kinematic parameters of body motion, the

direction (linear or rotational), duration and magnitude of motion.

Although the risk of injury is low, emergency physicians should know that amusement park rides could be related to inexplicable symptoms associated with damage caused by extreme conditions of roller coaster rides, so physicians should stay alert when patients mention that they attend an amusement park. Some cases presented in this review were correlated to pre-existing trauma or aneurism [30].

It is important to mention that in some cases the patient repeated the ride several times, like the case of macular Hemorrhage which describes 13 rides [12], the subdural hematoma describe at least 11 rides [19], and the acute Parkinson syndrome after ventriculoperitoneal shunt malfunction describe several rides [17].

A correct clinical interview must be the first step to the correct diagnosis suspicion of this kind of injuries, Physician should ask for visits to amusement park in the last 3 months to the patient when there is no apparent traumatic event, because some authors have reported that patients tend to minimize these events and avoid them during the medical interview [12] and other authors have reported cases where the onset of symptoms is 2 months after the visit to the amusement parks [20].

We try to make a correlation of the injuries with the G force applied by the roller coaster but it was very complicated because the articles usually do not report the G forces, we found it only it to articles and the G forces was 4.5 and 3.5 [10,18].

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