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Contribution of injury biomechanics to traffic collision reconstructions: A case report

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ABSTRACT

Traffic collision reconstruction tends to ignore the contribution of injury biomechanics to their investigation. This publication presents a case where the importance of injury biomechanics is highlighted. This case involves a collision between two motorcycles in the same riding party. One individual (Rider #2) claimed to have been hit from behind by another individual (Rider #3) while being on the shoulder of the road. Meanwhile, Rider #3 claims that Rider #2 performed a U-turn in front of them which caused the collision. Using the testimonies, medical records and physical evidence, it was determined that the collision occurred in the middle of the lane, with the motorcycle at approximately a perpendicular angle. Abrasions and contusions seen on the thigh of Rider #2 indicated contact with the front fairing of Rider #3′s motorcycle. Additionally, Rider #2 suffered a fractured clavicle which is indicative of a lateral impact. In an impact from behind, no lateral loading would have been applied to Rider #2′s shoulder. However, a perpendicular impact would have lead Rider #2 to fall to the pavement, shoulder first. Lastly, Rider #3, as well as her motorcycle, came to rest in the middle of the lane, which suggests that the collision occurred in the lane with Rider #3 traveling along the road near the mid-line. This case is an appropriate illustration of the worth of injury biomechanics when dealing with traffic collision reconstruction and why it should be included as part of standard reconstruction process.

1. Introduction

Traffic collision reconstruction is an important field, especially when considering the cost of insurance claims and cases of reckless behavior. However, due to their training and experience, experts in the field tend to rely solely on the physical evidence of the vehicles themselves and what they left behind on the road. Rarely are the individuals and their injuries appropriately considered in the investigation. Injury biomechanics already has a proven track record of success in the court of law [1–5]. Despite this fact experts in traffic collision reconstruction are typically ill-equipped to use this information as it isn't a requirement for accreditation for organizations such as the Accreditation Commission for Traffic Accident Reconstructionists (ACTAR). This paper aims to demonstrate how injury biomechanics can be used together with classic traffic collision reconstruction techniques to differentiate between conflicting testimonies and identify "What Happened?" with almost unarguable clarity.

The case used to demonstrate this point involves two motorcyclists who, in the course of an afternoon ride, collided with each other. In the aftermath of the incident, a legal battle ensued. Using scene evidence, injuries to the drivers and damage to their vehicle, the question: "What Happened?" was answered beyond a reasonable doubt.

2. Case presentation

2.1. Incident

The incident in question involves two recreational motorcyclists of approximately 30 years old riding as part of a three-motorcycle convoy. The motorcyclists were riding in a typical pack pattern with the leading motorcycle in position 1, closer to the centreline, while the second rider was in position 3, along the outside of the lane and the last rider, was also in position 1. For clarity and anonymity, the riders will be referred to as Rider #1 through #3 from their position on in the pack. The riders of interest are Rider #2, a male who was driving a 2007 Kawasaki Ninja ZX-6R and Rider #3, a female, who was riding a 2009 Kawasaki Ninja ZX-6R monster edition.

Approximately one hour after the start of the ride, the group turned around and started to head home due to unforeseen circumstances. On the way home, the group kept the same riding pattern. However, Rider #3 was slower than the rest of the group and, so, she lost sight of the group around a corner. Meanwhile, on the other end of the corner, Rider #2 decided to cross to the other side of the road to meet up with other bikers and so he prepared to perform a U-turn. Coming out of the turn, Rider #3 observed Rider #2 on the right-hand side of the road before the incident

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occurred. The two riders then collided. However, each rider claims a different version of events for the way the collision occurred.

What is known is that Rider #2 was hit by Rider #3 and both riders came to rest on the roadway. Rider #2′s final position was in close proximity to the impact location while Rider #3 was found further down the roadway with the motorcycle further down from her.

Both riders were eventually treated at the hospital and the following injuries were reported. Rider #2 was diagnosed with a right mid-clavicular fracture. The fracture was described as a distal third comminuted fracture and minimally displaced. Rider #2 also complained of pain to the upper left thigh and had abrasions and discoloration at the proximal part of the lateral aspect of his left thigh. Meanwhile, Rider #3 complained of chest, wrist, and neck pain as well as a sore left knee.

3. Method

The method used to investigate this case revolves around the injuries sustained. As is typical with most investigations, information about the event is missing, incomplete, or is provided by source(s) that could be considered biased and/or physically unable to recall events to a satisfactory level of preciseness. However, injuries are a factual basis which allows for powerful analyses and physics-based conclusions once compared with the available dynamics information.

In this case, there were no external eyewitnesses and therefore only the two riders can provide a description of events. However, due to the nature of the incident and the ensuing litigation, each party has a vested interest in the outcome and, therefore, risks being biased. These testimonies were compared and important details were analyzed objectively in order to identify the most likely scenario.

4. Injuries

The injuries sustained by each party are the key first step in understanding the incident. Therefore, great care is taken here to present the injuries and provide context to the mechanism of each injury. Focus is placed on the injuries of Rider #2 due to their relevance to the interaction between the two motorcycles. Less focus is given to Rider #3′s injuries as they are relatively benign and, therefore, lack detailed medical records confirmation.

4.1. Leg injury

Images of Rider #2′s left leg showed various abrasions and discolorations shown in Fig. 1. Non-lethal blunt force trauma causing abrasions and discoloration is a common occurrence in everyday life

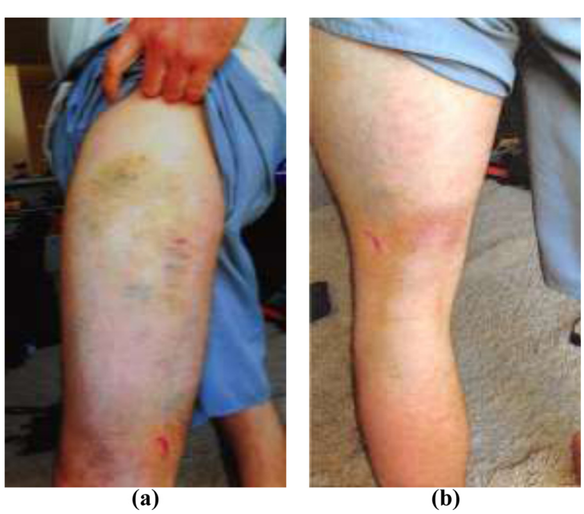

Fig. 1. Abrasions and discoloration to (a) side and (b) back of Rider #2′s left leg.

activities such as sports and can be seen as relatively harmless as they heal fast and rarely leave any permanent damage [6]. However, in forensics, the shape, placement, and pattern of abrasions and discolorations can offer insight into the object, its relative orientation with the limb and even force magnitude involved in delivering the blunt trauma [7]. Hence, abrasions and contusions are relevant from a biomechanical engineering perspective when determining impact and movement patterns as they provide an independent source of information regarding contact with an object. To understand these relations, the difference between abrasions and contusions should be established.

Abrasions are a common type of skin injury involving the surface of the skin. Typically, tangential friction causes abrasions [8]. Friction burns and road rash are typical types of abrasions seen in motor vehicle incidents. Other abrasion injuries can be associated with loads such as bites or similar application of force over a small area.

One such abrasion appears to be present on the side of Rider #2′s left leg above the knee, as a dark red semicircular crescent shape. Upon closer inspection, it also appears to be devoid of hair in the immediate vicinity of the abrasion indicating a tangential type of contact. This information can be used to determine likely contact points of Rider #3′s motorcycle, which, in turn, can then be used to determine the motorcycles orientation at the time of impact.

The discolorations are assumed to be contusions, which is an injury where small blood vessels rupture after the application of a blunt force [6]. The damaged capillaries then allow blood to flow around the tissue, which eventually produces a recognizable discoloration of the skin [7].

This discoloration can be seen on both views from Fig. 1 as various shades of blue, purple and yellow. View (a) of Rider #2′s left leg shows a large oblong contusion pattern centered on the lateral aspect of the thigh while view (b) shows a straight uniformly colored purple bruise on the more distal and posterior side of the thigh. These patterns can be used to match contact points with Rider #3′s motorcycle, which can then be used to determine both motorcycles orientation at the time of impact.

4.2. Clavicle fracture

Rider #2 suffered from a fracture to his right clavicle as a result of the incident. This fracture was reported as both a distal third and a mid-clavicular fracture on different occasions. Also, at least two bone fragments were reported as part of the comminution of this fracture.

Clavicle diaphysis fractures, like Rider #2′s, are most commonly caused by a lateral compressive load to the shoulder and is often associated with high-energy impact from either motor vehicle incidents (29.8%), falls (22.8%) or impact sports (30.1%) [9–11].

As the shoulder is subjected to a lateral compressive force (towards the midline), the clavicle and its articulations take the majority of the load. When this load is sufficient to result in a break of the clavicle, the fracture occurs at the mid-shaft in a large majority of cases (85%), as it did with Rider #2, since this location is where the cross section is not only minimal but also where the amount of soft tissue is scarce and cannot contribute to dissipating impact forces [12]. Mechanisms of injury that did not match Rider #2′s clavicle fracture as described in medical records include a) failure at the proximal articulation, the sternoclavicular joint (SCJ). SCJ fractures are rare and most likely to be caused by anterior to posterior forces [12]; and b) failure of the acromioclavicular joint (ACJ), the distal end of the clavicle. ACJ fractures are often associated with impacts to the superior aspect of the acromion (shoulder) or less commonly falls involving an outstretched hand [13].

5. Incident dynamics

The events were described by both involved parties but contain significant differences. This section aims to highlight these differences before being able to analyze them in the subsequent section.

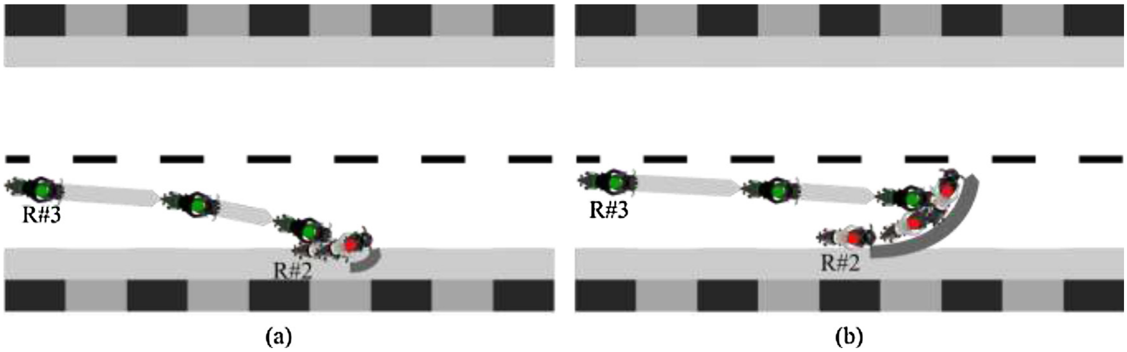

Fig. 2. Bird's-eye view illustration of description of the incident from (a) Rider #2 and (b) Rider #3.

5.1. *Rider #2′s description of the incident*

According to Rider #2, was pulled over on the shoulder of the road, at the edge between pavement and gravel. After the short stop, he pushed himself forward and into the lane slightly to get a better angle to shoulder check behind him when he was suddenly struck from behind.

In Rider #2′s mentioned that he believed the front tire of Rider #3′s motorcycle hit his rear tire causing her and her bike to flip over his motorcycle and hit him in the back of the shoulder and head. Rider #2 later rectified that Rider #3′s motorcycle hit him behind his leg causing her to launch off of her motorcycle and push his right shoulder forward which broke his collarbone. Rider #2 then landed on his hands and knees approximately one motorcycle length away from his knocked over motorcycle. According to Rider #2, Rider #3 landed between one and one and a half car lengths past where Rider #2 landed and her bike was even further away than she was.

5.2. *Rider #3′s description of the incident*

According to Rider #3, despite riding practically alone at this point, she was still riding in Position 1, which means, on the leftmost side of the traffic lane. As she took the turn, Rider #3 recalls her speed as approximately 60–70 km/h. Rider #3 then saw Rider #2 on the side of the road without his hands on the controls or brakes at a distance of 200–300 m. Rider #3 prepared to pass him but when she was approximately 5–10 m behind Rider #2, the latter raised his hands to his handlebars and began to roll into the lane. According to Rider #3, Rider #2 did not shoulder check or signal before attempting to perform a U-turn. She applied her brakes, which caused the back wheel of her motorcycle to lift off the pavement but failed to slow down in time or avoid impact. She estimates her speed at the time, as approximately 35 km/h.

Rider #3 believes her motorcycle was perpendicular to Rider #2′s at the time of the impact. The front of her motorcycle hit the frame of Rider 2′s as well his leg. Rider #3 described Rider #2′s leg as being down instead of on the foot peg. Rider #3 and her motorcycle then flipped over Rider #2′s motorcycle causing both rider's upper bodies to collide. As she did so, she flew through the air in a "Superman position" to later fell on her chest, chin and hands. According to Rider #3, she came to rest in the middle of the laneway while her motorcycle was further on down the road. Meanwhile, Rider #2′s resting position was closer to the point of collision.

6. Analysis

The individual aspects of each narrative were analyzed to assess their degree of consistency with the evidence. The analysis investigates the impact by starting at the lowest point of contact and moves up the motorcycle in a step-by-step fashion in order to delineate which narrative most likely occurred.

6.1. *Tire impact location*

The first important initial parameter of the impact is Rider #2′s leg position. In Rider #2′s version of the events, he states he was stopped with his left foot on the ground. Therefore, at the time of the impact, his leg would have been lowered, and so, likely as depicted in Fig. 3 below. Rider #3′s version of the events states that Rider #2 was performing a U-turn with his foot barely off the road. Rider #2 having his leg down during the turn is consistent with the technique used for turning on a dirt bike. Rider #2 learnt to ride a dirt bike at the age of 5 years old and then transitioned into driving a motorcycle in adulthood. Due to these statements and riding habits, it is likely that he would have his leg in a similar position as depicted in Fig. 3. Therefore in both scenarios, it is likely that Rider #2′s left leg was lowered and not on the foot peg.

The next important initial condition is where Rider #3′s motorcycle impacted Rider #2′s motorcycle. An asphalt abrasion to the right side of Rider #2′s motorcycles gas tank indicates that it presumably landed on its right side after the impact. Therefore, according to the principles of momentum transfer Rider #3′s motorcycle likely impacted the left side of Rider #2′s motorcycle. Apart from this damage, Rider #2′s motorcycle appears relatively undamaged.

In one version of events provided by Rider #2, Rider #3′s motorcycle struck his back tire without causing any damage. This scenario does not seem likely, as it does not explain the trauma to his left leg. His second statement suggests that Rider #3′s front tire hit the posterior aspect of Rider #2′s left leg. This second statement is closer in agreement to Rider #3′s claim that the front wheel of her motorcycle hit approximately on the vehicle's frame behind the leg.

Although the area of contact is similar between both accounts, neither completely explain the bruising pattern on the left leg and the lack of damage to the left side of Rider #2′s motorcycle. During the impact, Rider #2 received a large contusion on the lateral surface of his left thigh as well

Fig. 3. Motorcycle owner demonstrating stopped position on a 2008 Kawasaki Ninja ZX-6R.

as a contusion and crescent-shaped mark slightly above the posterior-lateral surface of his knee. These injuries do not match the shape or the height of Rider #3′s motorcycle front tire. However, it is consistent with Rider #3′s front tire hitting the solid steel frame of Rider #2′s motorcycle just behind his left leg. This explains the lack of damage to the left side of his motorcycle as the compliant front tire impacted and deformed against the relatively rigid steel frame. Fig. 4 shows the location of Rider #3′s front tire impact (A).

6.2. Injury pattern fit

The injuries shown in Fig. 1 were likely caused by the impact between the two riders. The side impact described by Rider #3 is most plausible and the following analysis shows how Rider #3′s motorcycle could have caused the injuries in question.

6.2.1. Vertical alignment

The pitch angle of Rider #3′s motorcycle was compared to the regions of the crescent-shaped mark and contusion shown in Fig. 1. To do so, Rider #3′s motorcycle was modelled with the back wheel rising from the pavement. The angle was then modulated to find the angle that best matched the injury pattern on Rider #2′s left thigh. The result can be seen in Fig. 4.

The large contusion on Rider #2′s hip matches the location of the front fairing of Rider #3′s motorcycle (C) and the crescent-shaped mark matches a notch found on both sides of the front fairing (#2). Unfortunately, because the front fairing of Rider #3′s motorcycle was torn off during the incident it was not possible to view the notch of the incident motorcycle itself in images taken at the scene. Instead, the notch shape was investigated during the inspection of a motorcycle of the same year and model. A close-up view of the notch found on a 2008 Kawasaki Ninja ZX-6R is included in Fig. 5 below.

6.2.2. Horizontal alignment

Further investigation was performed on the front fairing notch of Rider #3′s motorcycle to see if it could have caused the crescent-shaped mark on Rider #2′s leg (B). As previously mentioned, the height of the mark matches the height of the notch at the braking angle of Rider #3′s motorcycle but it is also important to investigate the lateral alignment between this injury pattern and the front of Rider #3′s motorcycle.

A dimensional analysis of Rider #3′s motorcycle revealed that the notches are approximately 6.3 in. away from the centerline of the motorcycle and approximately 3.8 in. away from the edge of the front tire horizontally. Therefore, Rider #3′s tire is able to impact Rider #2′s frame at location A without contacting his lower leg while the notch and associated fairing can impact his lower and upper thigh region (B and C) since they are offset horizontally from the tire by approximately 3.8 in.. Further, Rider #2′s riding stance prior to the collision places his calf forward of where the tire would have impacted. This means that there was enough room for the tire to hit the motorcycle and for the front fairing to

Fig. 5. Notch on the left side of the front fender of the 2008 Kawasaki Ninja ZX-6R inspected during the full-scale motorcycle examination.

come into contact with Rider #2′s thigh, thus leaving the marks identified as B and C in Fig. 4.

This lateral alignment, in turn, suggests a relatively perpendicular angle between the two motorcycles at the time of impact. A nearly perpendicular angle corresponds well with the dimensions previously described. In contrast, an impact where the motorcycles are oriented in a more parallel direction would not allow for the kind of damage seen on Rider #2 and his motorcycle. Such a sharp angle impact angle would likely have seen the front right fairing of Rider #3′s motorcycle impacted the left side of Rider #2′s motorcycle and left noticeable tangential damage. There were no such marks on the left side of Rider #2′s motorcycle.

6.2.3. Notch-crescent shaped mark injury assessment

In order to further confirm the alignment between the injuries and motorcycles, the front fairing of Rider #2′s motorcycle was investigated to see if it could cause this injury pattern of the crescent-shaped mark. First, the notch felt abrasive to the touch; and second, blue marking chalk (Irwin Strait-Line, blue 8oz, Model# 64901, Huntersville, NC, USA) was used to imprint the outline of the notch on the rounded surface of a thigh equivalent made of porous foam.

The resulting chalk imprint on the foam was then compared to images of Rider #2′s thigh as shown in Fig. 6. The chalk imprint can be seen as having a similar shape and curvature to the crescent-shaped mark on Rider #2′s leg. Additionally, the left side of Fig. 6 shows Rider #2 also had a contusion above the back of his knee in line with the crescent-shaped mark. This contusion could be attributed to the force of the associated fairings impact.

6.2.4. Fairing contusion injury assessment

In addition to the evidence shown relative to the crescent-shaped mark, the suggested position of the motorcycle agrees aligns with the large contusion on the higher portion of Rider #2′s thigh. Not only does the location of Rider #3′s front fairing and windshield match the location

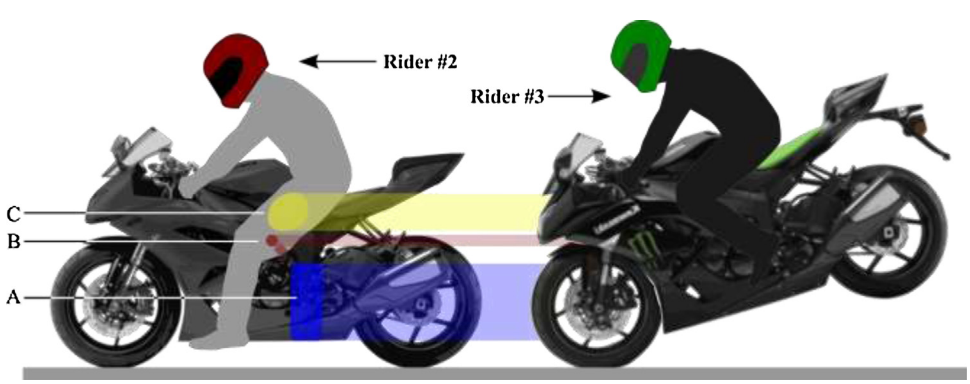

Fig. 4. Height of impacts to Rider #2 and his motorcycle compared to the height of various locations on Rider #3′s motorcycle at the matched motorcycle angle.

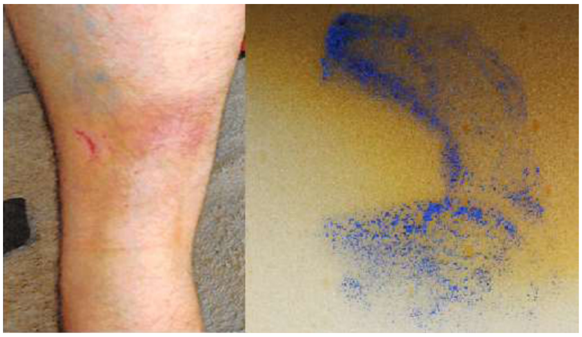

Fig. 6. Comparison of the abrasion on Rider #2′s leg and the imprint of the notch left on the foam.

of his lateral thigh during impact but also the large shape and size of the front of Rider #3′s motorcycle generally correlate with the size of the contusion. The location of the contusion is consistent with Rider #3′s version of the events and not Rider #2′s as the contusion would likely be more rearward.

Although Rider #2′s thigh contusion is large, it does not reason that his thigh took the majority of the impact. Although the fairing and windshield protrude past the steel frame of the motorcycle, the same is true for Rider #3′s front tire. However, the thigh is viscoelastic and would easily deform until the front tire impacts the steel frame. After which, the majority of the load would transfer through the stiffer tire on frame contact. In previous independent research regarding the formation of contusions, it was shown that contusions could occur after impacts of less than 1000 N [6]. The impact force in this crash was much larger than 1000 N, which further validates that the frame of Rider #2′s motorcycle absorbed the majority of the impact.

6.2.5. Fall-clavicle fracture assessment

According to the laws of inertia, after Rider #3′s motorcycle came in contact with Rider #2′s motorcycle frame and left leg, her motorcycle would have slowed down significantly unlike Rider #3 herself who would have continued to travel at a relatively unchanged speed. This would have resulted in her being ejected from her seat. Both Rider #2 and Rider #3 agree that, in the process, she collided with Rider #2. Rider #2 believes that Rider #3 hit the back of his shoulder, which caused his clavicle fracture.

Based on Rider #2′s statement, Rider #3 hit him from rearward direction. Based on this impact angle, she would have collided with the back of Rider #2′s shoulder with a posterior to anterior force, which is unlikely to cause a clavicle injury [14]. Such blows to the back of the shoulder would be more likely to cause scapular injuries [12]. Though blows to the posterior aspect of the shoulder can be responsible for displaced clavicle fractures, these loads must include a mid-line direction (medial) and overall compression of the shoulder girdle in order to load the clavicle for fracture. Similarly, a more likely mechanism would involve an impact originating from the right side as shown in Fig. 7.

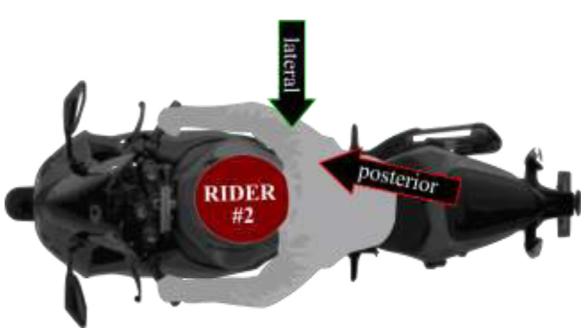

Fig. 7. Orientation of force on Rider #2′s upper body.

In fact, the lateral load associated with Rider #2′s clavicle injury is most often caused by falls or direct lateral compressive blows (see section 4). It is, therefore, more likely that a fall to the right side of his motorcycle caused the clavicle fracture. Clavicle fracture literature [15] suggests that a force between 2 to 4 times the bodyweight is sufficient to generate such a fracture given that the impact is along the axis of the clavicle (lateral from the shoulder).

Upon impacting the ground, his right shoulder would have been pushed medially (mid-line) which could have caused the mid-clavicular fracture. Therefore, this possibility also aligns with two previously stated perpendicular impacts; the first being the impact between the two motorcycles and the second being the impact between the two riders. The combination of these impacts would have violently pushed Rider #2 off his motorcycle and toward the ground.

6.3. Motorcycle momentum assessment

After contacting Rider #2 during impact, Rider #3 would have continued her trajectory past Rider #2′s motorcycle, and landed further down the roadway in a similar direction as her approach vector at contact. Simultaneously, her motorcycle would have followed along a similar path. Hence, if Rider #2′s motorcycle were positioned on the shoulder or at the edge of the roadway at the time of the collision, Rider #3 and/or her motorcycle would have likely come to rest on the shoulder or off the road entirely. Alternatively, if Rider #2′s motorcycle was in the middle of the lane and performing a U-turn, it is likely that Rider #3 and her motorcycle would have come to rest within the confines of the lane.

According to both Rider #2′s and Rider #3′s recollection her motorcycle came to rest on the roadway. This fact indicates that Rider #2′s motorcycle was more likely in the middle of the road at the time of impact.

7. Discussion

Multiple injuries were identified through the analysis previously presented. For ease of discussion, the table below aims to summarize these injuries. (Table 1).

The crescent-shaped mark on Rider #2′s leg shows typical signs of tangential contact with an object. The object appears to be the left side notch of the front fairing shown in Fig. 5. If Rider #2′s motorcycle had been aligned with the road as Rider #2 claimed, the contact between the motorcycles would have been more rearward or tangential and would now have correspond to the front fairing pattern identified.

The same can be said for the contusion found higher on Rider #2′s thigh. This injury is consistent with a lateral blunt impact and would not have been possible from a rearward angle. For such an impact, the majority of the bruise would be on the anterior side of the thigh.

Furthermore, a compressive load to the shoulder most likely caused Rider #2′s right clavicle fracture. This indicates a lateral fall onto his right shoulder. A more rearward oriented impact would have caused a posterior to anterior load on the back of the shoulder region, which is less likely to cause mid-shaft clavicular fracture and more likely to cause scapular injury.

Lastly, the momentum assessment of the two motorcycles shows that during a rearward impact, Rider #3′s motorcycle would more likely have come to rest on the shoulder of the road or in the ditch. This is inconsistent with the position where the motorcycle was actually described as coming to rest by both parties.

Table 1
Summary of mechanism injuries.

Injury	Mechanism
Notch-Crescent Shaped Mark	Abrasion or pinching
Thigh Discoloration	Blunt impact with a large object
Clavicle Fracture	Fall to the lateral aspect of the shoulder

These four aspects of the investigation all point towards the conclusion that the impact was more likely than not perpendicular in nature. This would place Rider #2 in the middle of the lane in a perpendicular orientation to the road. This is best represented by Fig. 2(b).

8. Conclusion

This case was resolved to the advantage of Rider #3 after the evidence previously described was presented. In comparison, two other engineering firms commissioned to answer the same question and who specialize in traffic collision reconstruction had not been able to meet the requirement for the balance of probabilities without the use of injury biomechanics as an indicator for the angle of impact and overall dynamics of the incident.

This case highlights the importance of considering injury biomechanics as a starting point for traffic collision reconstructions. All injuries provide information about the circumstances of their infliction, as injuries are the expression of the inertial and contact loads applied to the human involved in traffic collisions. It stands to reason that injury biomechanics should become part of the standard reconstruction process and included in future education requirements.

Declaration of Competing Interest

The work included was performed as part of a litigation case where the company (GTD Scientific Inc.) was hired to provide an expert opinion. However, the company (and authors) did not benefit from the outcome of the litigation. The conclusions reached as part of the work were based on sound forensic science and injury biomechanics principles and would have been the same in any other context.

Acknowledgements

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