Deconstructing a collision

Roger Wade, Brian Henderson and Ian Simpson take an in-depth look at the science of RTA neck injuries and outline the many factors to be considered in claims

Roger Wade is a consultant orthopaedic surgeon, Brian Henderson is the managing director of GBB (UK) Ltd, Forensic Collision Investigation and Research, and Ian Simpson is a barrister at London Chambers

'It only takes a search of court cases in this field to show that the claimant's advocate will usually rely on the medical expert and the defendant's advocate will base their argument on the engineering evidence.'

The Quebec Task Force defines whiplash as 'an acceleration-deceleration mechanism of energy transfer to the neck'. If an RTA occurs where this mechanism is present and the resulting forces applied to the neck are sufficiently large, a 'whiplash' has taken place. It is simpler to restrict the use of the term 'whiplash' to define this bio-mechanical phenomenon. Newton's laws of physics can be applied to whiplash and an objective measure of the energy transfer calculated. This is enveloped in a specific area of the science of accident reconstruction.

Whiplash injuries and associated symptoms are due to presumed underlying damage to the structures in the neck. Unfortunately, the symptoms that are described by the 'victim' are purely subjective, ie they are described by the claimant and there are no objective measures. A review of the medical literature can be applied to variables involved in the accident in an attempt to quantify the likely recovery.

When this type of injury is assessed in the medico-legal setting, these arguments are usually taken in isolation. It only takes a search of court cases in this field to show that the claimant's advocate will usually rely on the medical expert and the defendant's advocate will base their argument on the engineering evidence.

This method is clearly flawed. The medical expert cannot take the description of a 'written-off' car as meaning that the forces involved were large, just as a collision expert cannot ascertain whether a certain individual is likely to be at risk of injury based on the exchange of energy alone. This article will examine first the mechanics of a collision and then go on to consider the medical factors that may influence a whiplash claim.

Time delay

Unfortunately, the information required is usually not all available at the same time – the early medical evidence is gained from GP notes and the expert is usually only instructed later, sometimes even when the symptoms have settled. Collision experts are typically only involved if the case is felt to be in the group of low-velocity impacts – again, usually later on in the case. It is fundamental that these two aspects of this type of injury are considered together by experts who are privy to all the information. Only then can more objective conclusions be drawn.

The recent judgment of the Court of Appeal in *Casey v Cartwright* [2006] may promote a contraction in the timeframes in which the relevant expert evidence is obtained, but it is still probable that any injury symptoms will have settled before that process is complete.

Mechanical evidence

Accident analysis involves the assessment of vehicle damage, correlating this with full-size crash-test data and then carrying out momentum conservation calculations based on the laws of Newtonian physics. From these the change in velocity, the delta-v (D_v), that is experienced by the vehicle can be calculated. This is the objective measure of acceleration applied to the vehicle and subsequently correlates to the acceleration-deceleration mechanism to the victim's neck – the whiplash.

What happens during a collision?

Contact: the bullet vehicle makes initial contact and as it penetrates the target vehicle it applies force to it.

Momentum conservation: the applied force multiplied by the time increment for

which it is acting is the impulse. The momentum of the target vehicle is increased by an amount equal to the impulse. The bullet vehicle experiences an impulse of equal magnitude in the opposite direction in accordance with Newton's third law (see box, below). Thus, the momentum of the bullet vehicle decreases by this amount. By this process momentum is conserved. Momentum is not conserved, however, if an external force, such as braking, is applied during the collision.

Work of deformation: during impact the structures deform. The energy required for this deformation comes from the stored kinetic energy within the vehicles. Some energy is also converted to sound and heat.

Maximum engagement: at this point the vehicles will have a common velocity and deformation is at its maximum. What happens next depends on the proportion of elastic and inelastic deformation. Elastic structures will recover their shape and thus will reapply forces to the vehicles pushing them apart. Non-elastic structures will show permanent damage.

Momentum is conserved but kinetic energy is not conserved, as some is converted in creating sound, heat and permanent damage to the vehicles.

There are an infinite number of variations on the theme of the general collision described above.

The progress of a collision depends on the speeds and relative masses of vehicles and on their construction. The construction of a vehicle is crucial, as progressive collapse of non-elastic structures minimises accelerations to the occupants.

Restitution

A collision can be described in terms of its coefficient of restitution (COR). At its minimum (COR = zero) there is no elastic deformation. Theoretically, this type of collision will only occur at a very high-impact speed. In reality, almost any collision that takes place at an impact speed greater than 20mph is essentially inelastic, with a COR of zero.

For a collision to have the maximum COR (one) the impact speed would have to be zero or, if it were not zero, the materials from which the vehicles were constructed would have to be very stiff, such that they did not flex during the collision. The reason for this is that even elastic materials will generate heat, due to internal friction, when they deform and then reform during the course of a collision. This heat will represent an energy change to the system of colliding vehicles and so by definition the collision could not be perfectly elastic.

It is almost universally accepted by researchers that the COR increases as collision speed decreases.

For increasing values of impact speed, the COR decreases as elastic deformation becomes a smaller part of the total deformation. Vehicles do not have their own characteristic COR that they bring to a collision. Each collision is unique and the COR is a function of impact speed and the construction of each vehicle.

The COR of a collision is important, particularly in low-speed impacts, as it has an influence on the value of the D_v experienced by the target vehicle and, therefore, on the probability of whiplash injury to its occupants.

The construction of a vehicle is crucial, as progressive collapse of non-elastic structures minimises accelerations to the occupants.

Impact on the occupant

The impact force of the collision takes about one millisecond to pass through the vehicle. The momentum transfer causes the target vehicle to accelerate and every part that is attached receives just the amount of force to cause the same acceleration to all parts. The occupant is not rigidly attached to the seat and so does not receive force to accelerate at the same rate. This is seen as the occupant sinks into the seat and their maximum acceleration is delayed. The body of the occupant then catches up and accelerates past the normal seating position until restrained by the seatbelt.

The head is loosely attached to the body by the neck and its motion is further delayed. The maximum relative movement between the head and body occurs when the head accelerates past the body as the body is returning to the seat. Disparity between the motion of the head and body must be accommodated by the neck, and if the structural capabilities of the neck are exceeded then the result may be whiplash. It follows that the more momentum that is transferred to the struck vehicle during a collision, the more the motion of the occupant. It is the process of transfer of this momentum and energy and the resultant motions that may cause injury; this is studied in simulated crash tests by measuring head and chest accelerations (see 'Putting the 5mph injury threshold to the test' *PILJ*48).

Logically, it follows that accurate accident reconstruction provides a scientific answer to the likely momentum that has been transferred through the neck, and this provides a quantitative measure of the whiplash. This will be considered later, following the medical evidence with the application of D_v.

Medical evidence

We must always remember that medical evidence is not based on hard and fast rules such as the laws of Newtonian physics. The body has an infinite number

Newton's laws of motion

1) An object will remain stationary or continue in uniform motion in a straight line unless acted upon by an external force.

2) When an object of constant mass has a resultant force applied to it, the object will accelerate in the direction of this force. The magnitude of acceleration (a) will be proportional to the force (F) and inversely proportional to the mass (m). F=ma.

3) When two objects, A and B, are in contact, the force that A applies to B is equal in magnitude but opposite in direction to the force that B applies to A.

In an accident, the target vehicle will accelerate due to collision forces according to the second law. The bullet vehicle will experience forces equal in magnitude in the opposite direction according to the third law and so will decelerate according to the second law.

of variables and, as such, the study of the response to a specific injury is difficult. This is not to say that the studies that have already been undertaken on whiplash injuries are not valid, but it is important to quote them in context. To provide a better understanding of whiplash injuries we feel it is essential to avoid the 'all or none' argument of the injury: we are not here to argue the case for either 'chronic whiplash' or whiplash injuries not existing.

The medical factors involved in whiplash injuries are presented here with a view to allowing a more balanced judgement, so they can be used to help determine prognosis. However, this is just an overview – never lose sight of other articles and the pros and cons of each. A good expert should know whether papers cited in cross-examination are relevant: it is not acceptable just to provide a one-sided argument; a range of opinions should be included. It is important to remember that all articles have their limitations and they should not be used to discount evidence.

The medical evidence can be broken down into a number of study types:

- classification of injury;
- clinical studies of whiplash victims and follow-up of symptoms;
- controlled studies of volunteers in crash tests;
- population studies of whiplash injuries in different countries;
- the study of neck pain in the general population; and
- the quest for the objective marker for whiplash-injury victims.

Classification of injury

There are a number of studies that classify whiplash injuries. One that is validated and widely used is the Gargan and Bannister scale (see below). This places victims in various groups based on how restrictive their symptoms are; unfortunately, these are purely subjective. The Quebec Task Force added physical signs to their classification (also shown in the box below), but only the distinction between grade 2 and grade 3 has objective signs.

It must be remembered that grade-3 symptoms rarely occur in whiplash-type injuries and probably do represent a structural problem that would show on further investigation.

Other, more complicated, questionnaires exist that allow percentage figures to be applied to the symptoms suffered. On face value, this may allow the disability to be more accurately assessed, but does not get past the fact that it is still based on subjective reporting of symptoms.

Many of these scales are used in clinical papers to assess the progression or resolution of symptoms. Although this is better than not using any classification system, it certainly has its flaws. The scales are subjective but do allow severity of the whiplash injury to be quantified. A medical report should include reference to these established scales in its assessment of this type of injury.

Clinical studies

There are a number of studies looking at recovery following whiplash-type injuries. The studies base recovery on the scales described above. In their series Gargan and Bannister quote a complete recovery in 38% of patients; 30% with ongoing non-intrusive symptoms; 30% with ongoing intrusive symptoms; and 2% with disabling symptoms. Residual disability with regard to sporting activity at two years was shown to occur in 28% (*Murray et al* 1993). The rate of recovery showed an interesting trend: victims with symptoms at three months usually continue with some symptoms. Palmer and Raymaker showed that at six months over 50% of victims had pain, at 12 months this had fallen to 40% and at two years it was 22% (see box, 'Relative risk of long-term problems', on p9 for further examples of factors to be considered).

A number of studies have also looked at the success of treatment following whiplash. It is well documented that collars make no difference, non-steroidal anti-inflammatory medication affords benefit only in the short term, physical therapy is no better than self-help, and surgery is only indicated in specific groups of severe whiplash with structural damage.

There is certainly a psychological element to chronic whiplash injuries and this is also well documented. Quantifying the true contribution from this element of a chronic injury is probably impossible. It is likely that certain personality types are more prone to chronic injuries, but in the eyes of the law these individuals have to be taken as they are at the time of the accident. If there is felt to be a large contribution from psychological overlay then an expert in this field should be instructed. This is not necessarily the case in the early stages of the injury, except to say that a significant psychological response to the accident should be dealt with by an expert in this field.

Overall, the clinical factors of each case should be considered on an individual basis. Expert opinions based on

Scales of classification of injury

Gargan and Bannister scale

Group	Symptoms
A	None
B	Symptoms not interfering with occupation or leisure
C	Symptoms restricting occupation or leisure with or without use of analgesia, orthotics or physical therapy
D	Loss of occupation, continuous use of analgesia, orthotics, repeated medical consultations

Quebec Task Force classification

Group	Symptoms
0	No complaint about neck and no signs
1	Complaint of neck symptoms and no signs
2	Neck symptoms, tenderness and decreased range of movement
3	Neck symptoms and neurological abnormality

Relative risk of long-term problems

There are a number of clinical factors that have been shown to affect the outcome of whiplash injuries. These are summarised below:

Clinical factor	Author	Relative risk (if quoted)
Female	Hohl et al 1974	Worse
Seatbelt	Christian 1976	1.5
Headrest	Kahane 1982 Minton 2000	0.9 Non-predictor
Awareness	Ryan et al 1994	15
Pain distribution	Squires et al 1996	8
Previous whiplash	Khan et al 2000	5
Abnormal examination	Norris et al 1983 Farbman 1973	Worse Non-predictor
Osteoarthritis	Maimaris et al 1998 Hohl 1974 Friedberg et al 1963	4 Worse 1.5
Abnormal neurology	Maimaris et al 1998	3
Rear impact	Spizter et al 1995 Deans et al 1987	2 Worse
Front-seat passenger	Allen et al 1985 Deans et al 1987	3 Worse
Age (over 31)	Hohl et al 1974	Worse
Age (over 50)	Nygren et al 1984 Deans et al 1987	1.5 Worse
Age (over 60)	Gotten et al 1956	Worse
Attendance hospital	Hohl et al 1974	2
Early onset symptoms	Deans et al 1987 Hohl et al 1974 Farbman 1973	2.4 Worse Non-predictor

The list is not exhaustive and you can see that some factors will have much higher risk in one study, while in other studies they do not. Some are just not quantifiable. These factors give guidance to which victims are at more risk and should be included in the history of a whiplash injury and in determining the prognosis.

reports that do not document these factors add little value in assessing a whiplash claim. All these studies should be taken in context, as the study groups are not controlled and the injury mechanisms may vary considerably.

Controlled crash studies

The role of crash testing and the study of injury are focused mainly in the field of low-velocity impacts. It is logical that in a low-velocity impact the occupant is less likely to sustain an injury and any injury should be less chronic.

Unfortunately, this is where the logical quantitative application of Newtonian physics clashes with the subjective evidence of the medical literature. This is not to say that either is right or wrong, or that each has equal weighting in a specific case. Evidence from both fields should be considered by experts in those fields and from this a considered and balanced opinion can be obtained.

As already mentioned, the D_v of the impact is significant in whiplash cases. A number of studies have shown that a D_v of less than 5mph is unlikely to cause significant injury (see 'Studies of low-velocity collisions' overleaf). There may be symptoms for a few days, but not beyond this, and certainly not chronic symptoms. What is most illustrative of the forces involved in low-velocity impacts is the comparison made to activities of daily living (*Allen et al* 1994). Essentially, the forces that occur on the neck during a low-velocity impact are like sneezing, or slumping into a low chair.

Because studies involve volunteers in crash-test conditions, evidence based on such research may be discounted on the grounds that the victim is aware of the impending impact, they are young or the claimant fits a group of individuals at special risk of injury. However, this research should not be ignored simply because the volunteers do not exactly match the claimant.

Whiplash in other countries

There is definitely a cultural difference in the outcome of whiplash injuries. This has been studied in areas where compensation is not readily available, where there is an adversarial legal system or where claimants have to fund part of the claim themselves. In these instances, whiplash has been shown to be less common. This gives insight into the amount of suffering that victims describe following injury in a medico-legal setting, but it is difficult to apply in the argument for or against an individual claimant.

Neck pain in the normal population

There is certainly an underlying rate of neck pain in the general population. Overall, this is in the order of 40% on a yearly basis.

If a patient is at risk of neck pain on a cumulative basis, there is a point in time when they would have, on the balance of probability, developed neck pain naturally. Is it just that this episode of neck pain has coincided with the ongoing litigation? The link to the accident should be weighed on the balance of probability. This is certainly more relevant in individuals with pre-existing cervical spondylosis.

Casey v Cartwright
[2006] EWCA Civ 1280

Studies of low-velocity collisions

Author	Subjects	Type	D_V (mph)	Injuries
Szabo 1992	5 volunteers (3 male)	MRI before and after	4.8	Less than one day
McConnell 1993	4 volunteers (all male 25 to 43)	Experimental crash	1.8 - 4.9	No symptoms
Ono 1993	3 volunteers (all male 22 to 43)	Experimental crash	2.4 - 4.8	No symptoms
Siegmund 1993	Two males	Looked at forces in bumper cars	3.7 - 4.6	No symptoms
West 1993	Five men (25 to 43)	Experimental crash tests	1.0 - 9.9	Minor symptoms in high D_V
Geigl 1994	25 volunteers (2 females; 20 to 60)	Tried various rotations	3.6 - 7.2	No symptoms
Matsushita 1994	26 volunteers (22 men)	X-ray and MRI analysis	1.5 - 3.5	Maximum symptoms 2 to 4 days
Castro 2001	n/a	Placebo crash tests	0	20% sustained injury
Brault 1998	42 volunteers	Experimental subjects	2.4 - 4.8	Maximum 2 days
Castro 1997	19 volunteers	Experimental tests	5.2 - 8.5	Few minor symptoms
Neilson 1997	7 male volunteers	Found D_V frontal impact 12 to 20	1.0 - 6.6	Few for a few hours

Objective testing

There is no objective test for a whiplash injury. The only objective results are those found in the more severe group of injuries. These will have neurological abnormalities or other findings on further investigation. Fractures or dislocations would be visible and, although they have been caused by a whiplash injury, they are a notably different group.

Investigations do give some helpful information. The presence of long-standing osteoarthritis has a bearing on the outcome of whiplash injuries. The likelihood that symptoms last longer is well documented in the literature but it must be weighed against the fact that even asymptomatic individuals with osteoarthritis will get symptoms sooner than those with no osteoarthritis.

Summary

We have reviewed the arguments for and against the likelihood of a whiplash injury occurring. Is it possible to narrow the range of opinion following this type of injury from one which, at first glance, covers a wide scope from no damage to a permanent disability? To do this all the evidence should be considered (see 'Summary of factors in whiplash cases', right) and a range of opinion formulated for that individual.

Evidence from a medical point of view should include a thorough review of the case with all the associated factors and hopefully some indication of the accident mechanics.

A 'cut and paste' report, or one lacking in detail, by an expert with little or no interest in the field, who has not taken the time to consider all the medical factors is unlikely to be helpful to any concerned in the forensic process or, ultimately, the court.

Likewise, the engineering evidence of a low-velocity impact should not be accepted on face value and should be submitted by experts with a proven track record in this type of work.

It is not acceptable for a medical expert to give an opinion on a 'whiplash' injury without some explanation as to why and how the injury falls into that part of the injury spectrum and the range of expert opinion, nor is it acceptable for an expert to contend that no injury has occurred based solely on the low-velocity impact argument.

There is a middle ground, which allows that when all the evidence is considered for an individual case, the injury prognosis can be determined within a reasonable range of expert opinion to the standard of proof required for civil litigation. ■

Summary of factors in whiplash cases

Injury less likely	Injury more likely
Low-velocity impact	Significant damage to vehicles
Symptoms minor	Symptoms recorded in notes early on
No visit to GP	GP visits for analgesia
No recorded subjective signs early on	Objective and/or subjective signs recorded early on
No hospital visit	Hospital visit and X-rays
Fit and healthy individual	Other associated medical problems
Favourable clinical factors	Numerous clinical factors