Simulation of a Typical Camel–Vehicle Collisions (CVCs) in Saudi Arabia

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ABSTRACT

The camel–vehicle collision (CVC) problem has been increasing in Saudi Arabia and countermeasures are urgently needed to alleviate the heavy losses from such accidents. Modeling of a typical CVC has been created in a sagittal, and frontal planes to identify the common mechanisms of spinal injury of driver. In this work, computer simulations have been performed using a Multibody dynamic model of the cervical and thoracic-lumbar spine, where rigid bodies are connected by articulated joints and spring-damper elements. The internal neck forces Principle Virtual Power of Neck (PVPn) was applied at inter-vertebral levels for various impact speeds. PVPn was then correlated with real world crash data of neck injuries. It has been shown that PVPn at each intervertebral level correlates well with the crash data and can be used as a predictor of neck injuries.

محاكاة لتصادم المركبات مع الجمال السائبة في المملكة العربية السعودية

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الكلمات الدالة

اصابات العمود الفقري، محاكاة الجسيمات المتعدده، خطوره، القدره الافتراضيه، الجمال السائبه

المُستلخص

تعتبر مشكلة الحوادث المروريه للجمال السائبة في المملكة العربية السعوديه من المشاكل السائده خلال السنوات الماضيه. وهذا يتطلب دراسة المشكله وايجاد حلول كفيله بالحد من الخسائر الكبيره الناجمة عن هذه الحوادث.
تم في هذه الدراسه عمل نمذجة لأكثر أنواع التصادم الشائعة بين المركبه والجمال السائبة من الناحية الأمامية والجانبية ودراسة ميكانيكية اصابات العمود الفقري للسائقين خلال التصادم.
تم إجراء محاكاة حاسوبية للفقرات العنقيه والصدريه والقطنيه في العمود الفقري للسائق باستخدام نموذج ديناميكي متعدد الأجسام حيث تم تمثيل نظام العمود الفقري بواسطة جسيمات صلبة مرتبطه بمفاصل بينيه ومنظومه من النابض والمثبط.
قامت الدراسة باستخدام بيانات واقعيه من الحوادث المروريه لتحليل القوى بين الفقرات العنقيه وتطبيق نظرية القدرة الافتراضيه عند اصابات العنق نتيجة تصادم المركبات مع الجمال السائبه عن سرعات مختلفه.
أظهرت الدراسة ارتباطا وثيقا بين النتائج النظرية والتجارب العملية مما يعني امكانية استخدام نظرية القدرة الافتراضيه كمؤشر لاحتمالية اصابات العنق في الحوادث المروريه.

Introduction

Motor vehicle collisions with large animals occur in areas where these animals reside. A worldwide issue of importance to health care professionals is the growing incidence of large animal wildlife motor vehicle collisions. Globally, the most common large animals involved in motor vehicle collisions are kangaroos in Australia; camels in Saudi Arabia; and deer, moose, and bear in parts of Europe, Japan, Sweden, the United States, and Canada (Danielson et al., 1998, Farrell et al., 1996, Abu-Zidan et al., 2002, Al-Ghamdi and Al-Gadhi, 2004). Large animal collision impacts produce a distinct pattern of injury that is different from other motor vehicle collisions; there is a higher prevalence of injuries to the patient's head, neck, brain, and upper torso area (Larry and Conway, 1999).

Between 1990 and 2010, Camel Vehicle Crashes (CVCs) resulted in 5,630 injuries and 1360 deaths in Saudi Arabia (MoI, 1970-2010). Summaries of traffic accident data show that more than 600 camel crashes occur annually. Injuries were found to be four times and deaths six times more common in accidents resulting from camel collisions when compared with other causes of accidents (Al-Amro et al., 1996, Ansari and Ashraf, 1998). This kind of accidents contributes in the progressive increasing of Spinal Cord Injuries (SCIs) in Saudi Arabia in the recent years (AboAbat, 1999). Of 28 studies found on prevalence and the incidence of SCI in literature, the present incidence of SCI in Saudi Arabia is the highest rate ever reported in 85% of developed and developing countries (Al-Shammari, 2001).

Camels are animals of the desert. They are long-limbed animal standing approximately 2 m at the shoulders and weigh up to 600 kg (Ljungren et al., 1990). Quite a few camel breeding areas are adjacent to highways, and may or may not be fenced. The fencing is often interrupted at places by the camel owners to enable the herd to cross roads without going through the underpasses. Camel collisions are common in the evening time or early morning as camels who stay in the desert, mostly unsupervised, move around in herds of 4-6, often coming on to the roads without warning. They appear unexpected as a herd on the road. There is no space or chance for the driver to manoeuvre or swerve to avoid the collision (Ansari et al., 1998).

A large number of victims of these crashes continue to present at the hospitals. CVCs have been a concern for the highway patrols and other government agencies. Previously the car driver was penalized for any death or injury to the animal from these accidents. Compensation had to be paid by the driver to the owner of the camel. Therefore, some camel owners have been known to push their animals onto the highways after sunset to claim compensation after the accidents. This has now been stopped and recent legislation imposes penalties on the camel owners for letting their camels stray on the highways.

The Ministry of Transportation (MoT) has applied several infrastructural measures during the past 20 years to prevent animal vehicle collisions. However, past researches have shown wide experience among countries in dealing with the problem, but neither unique solutions nor consistent results have been found (Almkvist et al., 1978, Aberg, 1981, Lehmitimaki, 1984, Bjornstig et al., 1986, McCann et al., 1988, Al- Ghamdi and Al-Gadhi, 2004). Although some remedies were found to be effective in some areas, they were not effective at other sites. The relative effectiveness and cost of different methods is poorly understood, and evaluations regarding the effectiveness are lacking, which leaves many skepticisms about specific implementation strategies.

The mechanism and pattern of injuries related to CVC vary as a result of direct (primary) and indirect (secondary) collisions, and depending on the vehicle speed and the animal hit (Larry, and Conwa, 1999). Every camel crash is unique. Wild animals are very unpredictable and tend to appear very suddenly. The speed at which the camel colliding the vehicle, and the size and design of the cars are important factors (Al- Sebai and Al-Zahrani, 1997, Ansari et al., 2001, Ansari and Ashraf, 1998). Also, the relation of the injuries to the impact of the camel and the deformation of the car are thus of primary interest. From in-depth crash reconstruction studies, it is possible to discover more about the biomechanical characteristics of these accidents and the mechanisms of related injuries. Such information will definitely lead to improvement in early management of CVC victims and help the manufactures to produce cars crash-worthy enough to give its passengers protection for possible accidents.

The most common injuries in the CVCs are low cervical spinal injuries, because the occupant tries to adopt a protective flexion posture to avoid a direct hit. A significant number of casualties admitted to the spinal units in Saudi Arabia were injured due to camel collision car accidents (Ansari and Ashraf, 1998, Al- Sebai and Al-Zahrani, 1997). Of the victims with cervical spine injuries, 25% also have an associated head injury. Injuries are either localized to the occipital region or diffuse. Isolated injury to the neck resulting in dissection or occlusion of the internal carotid artery has also been reported (Ansari et al., 1998). A part from a few, single hospital based studies on CVC, no indepth investigations have been undertaken on spinal injury from camel collisions.

In many previous studies, numerical or physical models have been developed to investigate neck injuries. A number of neck injury criterion like the Nij, (Klinich et al., 1996, Kleinberger et al., 1998) and NIC (Bostrom et al., 1996) have been investigated using these models. However, none of them can be used in the case of camel accidents. Furthermore, there has been little work investigating the risk of neck injuries received by occupants in real accidents and comparison with the calculated injury criteria.

Sturgess (2001) has proposed the Peak Virtual Power (PVP) as a reliable neck injury criterion particularly for intervertebral soft tissue injuries. In order to compute power, intervertebral forces and motions play important roles.

This study further investigates the intervertebral forces and motion using a simplified model of the spine and demonstrates their efficacy in estimating risk of neck injuries in camel collisions.

A 2D multibody model of the whole spine has therefore been developed in Working Model software. The models were validated against the IIHS frontal barrier crash tests and two typical cases of camel impacts. The validated models were then used to analyse the behavior of driver/vehicle kinematics and the neck forces and motions at inter-vertebral levels for various impact speeds.

The paper first gives an overview of the severity of neck injury in camel crashes. This is followed by a description of the models developed and their validation. The simulations developed are then presented along with the results of the simulations and their analysis.

Severity Of Neck Injury

Historically, vehicle change-of-velocity (Delta-V or ΔV) and the resultant responses of the human occupant have been the most commonly used index for reporting injury risk in various types of real-world motor vehicle collisions. Cervical spine fracture thresholds in real-world frontal and rear-end crashes do differ with Delta-Vs (Krafft, 1998, Norin et al., 1997, Otte et al., 1997). In analyses of injury risks in real-life collisions, it is important to determine adequate, valid and reliable impact severity parameters which influence the injury risk (Kullgren, 1998). The possibilities of using different impact severity parameters in retrospective reconstructions methods are limited. Most reconstruction methods use the Equivalent Energy Speed (EES) or Delta-V (Zeidler et al., 1985) to describe impact severity. Attempts have also been made to estimate mean acceleration. However, other impact severity parameters may better relate to injury risk. A study by Kullgren (1998) showed that mean and peak accelerations separately better explain the overall injury risk than does change of velocity. Since the injury risk may depend on several parameters in the crash phases of an impact, it is important to have better reconstruction methods, where adequate severity parameters can be measured or reconstructed with accuracy.

Currently there is no any relationship found between neck injuries received by occupants in collisions with camels and the severity of these crashes. The severity of neck injury can be identified by using the MAIS-ΔV curves for both restrained and unrestrained occupants. Based on data collected from real word accidents in Saudi Arabia, the relationship between MAIS and ΔV has been found to vary between a square and cubic manner (Sturgess, 2002, Al-Shammari, 2011). The results are shown in Figure 1.

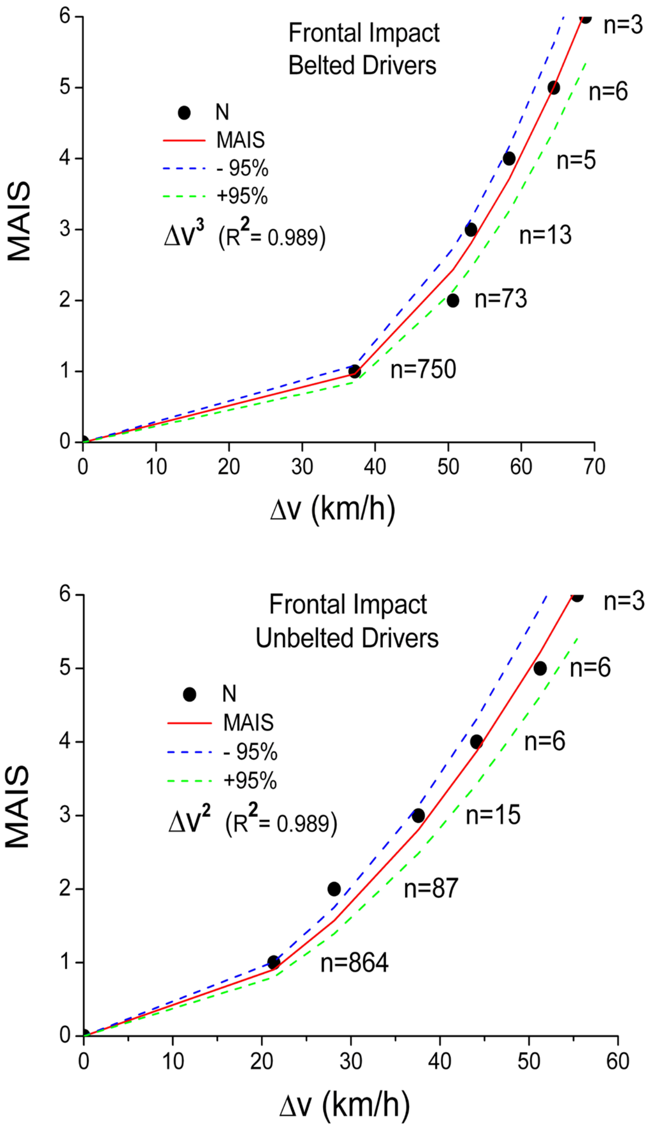


Figure 1: MAIS vs Delta-V for frontal impact, belted and unbelted drivers, for neck injuries

It can be inferred from above graphs that ΔV3 gives the best correlation for belted drivers, whereas for the unbelted drivers, the relationship between MAIS and ΔV is quadratic. On this basis Sturgess has showed that unrestrained occupants suffer higher injury levels at lower ΔV than do restrained occupants, because they are subject to higher Peak Virtual Power (PVP) inputs for a given ΔV (Sturgess, 2001 and 2002). As stated by Sturgess (Sturgess, 2002), the high degree of correlation demonstrates that, by making very simple assumptions about idealized impact types, a simple theory can account for 85–90 per cent of the injuries obtained from Co-operative Injury Study in the UK (CCIS – Phase 7) and NASS-CDC Databases. The fact that all injuries require an expenditure of energy means that energy methods are independent of injury mechanisms; therefore, PVP is a good candidate for a universal injury criterion which can be correlated with real-world injury experiences. Furthermore, energy is the only physical quantity that remains unchanged at all scales, and so PVP can be applied at the micro, meso and macro scale.

Mulation Of Camel Collision

In this study, impacts of a typical passenger car have been simulated with a typical dromedary camel. The camel is taken to be impacted either form the side or from behind in the sagittal plane, as these were considered to be the most common orientations of crashes with camels as seen from field data in Saudi Arabia (Al-Amro et al., 1996; Al-Ghamdi and Al-Gadhi, 2004).

Figure 2 shows the initial configuration of the model. As it is shown, the modelling of camel collision consisted of three systems combined in one MBD model: the car; the camel; and the driver dummy in the sagittal plane.

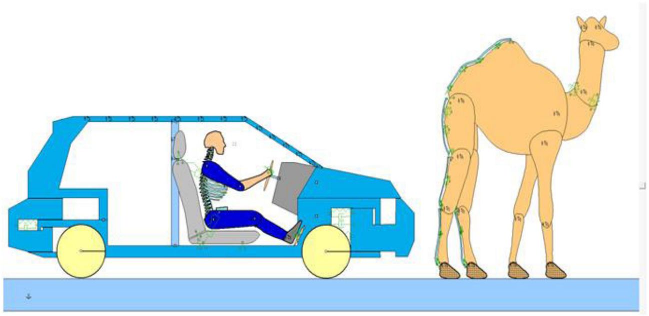


Figure 2: Model of camel collision in sagittal plane

1. Car model

The car model used for the simulations was developed using the data for a Toyota Corolla car. The vehicle has been modelled from regular geometrical shapes representing rigid bodies which are joined in an appropriate way to consider the effect of the energy dissipation at the moment of collision as well as characteristics of body deformation. The pedals and the wheel were modelled as rigid elements joined to the body through bracket joints. The details of the main car parts are provided in Table 1, and further details can be found in Al-Shammari and Sturgess (2012).

Table 1: Mechanical properties of vehicle

Element	Parameter	Value
Body of vehicle	Mass	800 kg
Front bumper	Mass	150 kg
Rear bumper	Mass	150 kg
Armchair assembly	Mass	22 kg
St. wheel/pedals	Mass	28 kg
Wheels	Mass	50 kg
Crash zone	Stiffness, k	1500 N/m
	Damper coefficient, b	7× 105 N.s/m

2.Driver model

The model of driver was created in a sagittal plane. The main parts of the human body modelled in are the head, spine, rib cage and the upper and lower limbs. The elements of the model were joined by articulated joints as open kinematic chains and additionally joined with spring-damper elements. Each of the muscles and ligaments have been modelled using appropriate spring and damper elements. The upper and lower limbs were connected by a pivot with a rotational spring-damper systems. The vertebral spine model includes 24 solid vertebrae, muscles, ligaments, inter-vertebral joints and discs as shown in Figure 3.

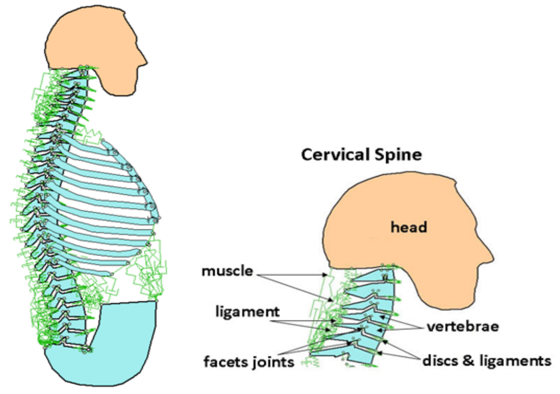


Figure 3: Modelling of the head and the whole spine in the sagittal plane

The geometry of the spine and the vertebral masses, as well as the mass moments of inertia were imported for a 75 kg male by using Rhinoceros Nurbs Modeling v3.0 SR5 and SolidWorks Office Pro 2007 Softwares. Material properties were assumed to be of a homogenous bone structure with a density of 1.5 (g/cm3). Material properties for cervical, thoracic, and lumbar spine discs were obtained from Yoganandan et al. (2000), White and Panjabi (1990) and Gardner-Morse and Stokes (2004) respectively. More details about the driver model can be found in Al-Shammari and Sturgess (2012).

The driver was then inserted in the vehicle model and joined by spring-damper elements representing the flexible connections between the human body with the armchair, pedals, seat belts and steering wheel as shown in Figure 4. The stiffness and damping coefficients of these elements are given in Table 2.

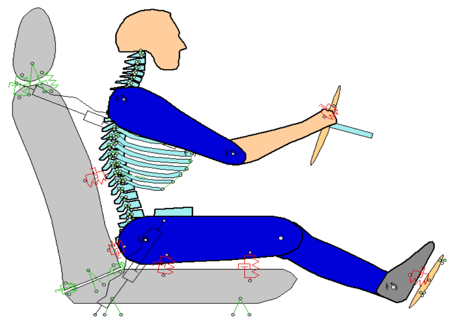


Figure 4: The connections between the driver and car in the sagittal plane

Table 2: Stiffness and damping values for driver/car contact points

Contact Point	k, Stiffness [N/m]	b, Damping [N.s/m]
Hand-Steering wheel	5000	50
Foot-Pedal	500	50
Leg-Seat	5000	1000
Sacrum-Seat	3000	1000
Sacrum-Backrest	8000	1000
Thorax-Backrest	1500	1000
Lower seatbelt	3 × 105	5000
Upper seatbelt	1 × 105	500

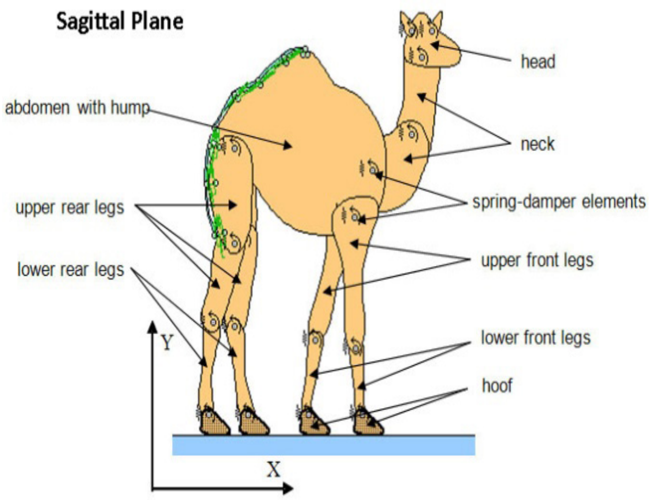
3. Camel model

Dromedary camels are one humped camels characterized by a long-curved neck, deep-narrow chest, and a single hump. Male dromedaries, in comparison to females, are about 10% heavier, weighing 600-800 kg, and are about 10 cm taller at shoulder height, measuring 1.8-2.0 m (Al-Habardi, 2000). The model of a typical adult camel has been made as per the anthropometric dimensions provided in Table 3.

The camel's body was divided into a head, neck, abdomen wih single hump and the front and rear legs. These elements of the anatomical structure were joined by articulated joints as an open kinematic chain and additionally joined with rotational spring-damper elements ($k\Phi$ = 5729 Nm/rad, $b\Phi$ = 57 Nms/rad) to capture the correct stiffness and kinematics. The movement of the camel models have been analysed into sagittal and frontal planes (Figure 5). Table 4 presents the mass moment of inertia of the main parts in the camel models. The typical mass of the camel was assumed to be 700 kg (Al-Habardi, 2000).

Table 3: Physical properties of a typical adult camel (Al-Habardi, 2000)

Property	Dimension (cm)
Ear's height	10
Width of eye	8
Distance from the front of the face to the gland	60
Length of neck	150
Distance between shoulder's joint and flank's joint	150
Length of tail	60
Distance from the tip of the hump to the ground	235
Distance from withers to the ground	205
Distance from withers to elbow pad	80
Distance from elbow pad to knee	60
Distance from knee to hoof	60
Distance from stifle pad to flank	80
Distance from stifle pad to hock	80
Distance from hock to hind hoof	60
Distance from one end of the hoof to the other	25
Distance of hoof joint to toenail	25



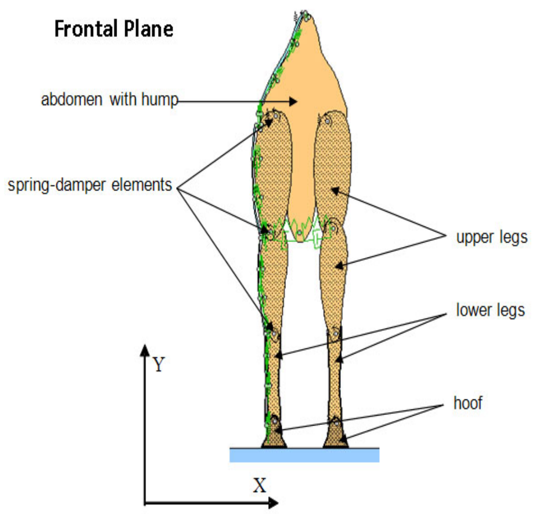


Figure 5: Coordinates of the camel models for the sagittal and frontal planes

Table 4: Moments of inertia, and mass of parts of camel's body

Parts of Camel's Body	Mass (kg)	Iz [kg.m2]
Sagittal Plane		
Head	20	0.3
Neck	35	1.1
Abdomen with hump	502	72.2
Upper front legs	12	0.8
Lower front legs	8	0.2
Upper rear leg	46.7	1.6
Lower rear leg	6	0.2
Hoof	1	0.26
Frontal Plane		
Abdomen with hump	502	49.9
Upper legs	58	1.8
Lower legs	14	0.2
Hoof	1	0.028

4. Models validation

First, the car model has been validated against available IIHS tests data for the same vehicle in frontal barrier tests (Iwamoto ET AL., 2002). Figure 6 shows a comparison between the acceleration and velocity of the vehicle based on the simulation and the IIHS tests. Since the peak accelerations as well as the acceleration pulse for both are similar, this was considered a good match and the car model was considered acceptable for further use. Then the camel collision modelling was validated using recorded crash data. Results from the simulation were compared with those from the recorded data in an attempt to validate the model. Figure 7 shows the points of impact in the crash. Points marked as '1', '2' and '3' are the points where the camel first touches, where the legs come in contact with the car and where the camel back comes to rest on the car top respectively. It also shows the same locations as observed in the simulations. From the analysis of these two camel crash cases, it can be seen that the simulation results are fairly close to the observations in the crash. It can thus be concluded that the camel model well predicts the camel kinematics and can be used for preliminary analysis of camel crashes.

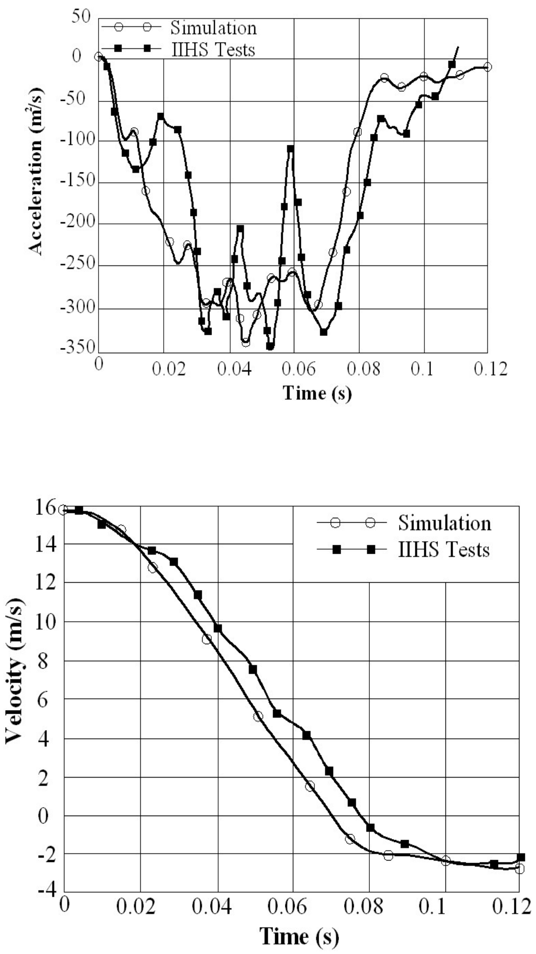


Figure 6: Comparison of vehicle acceleration and velocity obtained from simulation results and IIHS test data

Figure 7: Crashes showing the contact for the camel with the vehicle in each Case

Results And Discussion

Camel collision simulations were conducted at common impact speeds of 27, 80, and 120 km/h using the car and the dummy models described above. The simulations were run for the belted as well as the unbelted driver. A total of 6 simulations have thus been performed and the kinematics of the occupant and of the spine have been analysed. Intervertebral forces and velocities have then been used to compute the PVP in the intevertebral and levels and have been compared with incidences of intervertebral injuries in camel collisions obtained from real world accidents.

In order to estimate the risk of neck injuries, Sturgess has argued that Principle Virtual Power (PVP) could be a better predictor of the likelihood of injuries. This study investigates the PVP in the collision of camel and how well it predicts the likelihood of neck injuries. For the following neck injury evaluation, the PVPn of Neck is based on the acceleration and velocity change of the neck (Sturgess, 2001).

The Peak virtual power at each intervertebral level can be defined in Eq.(1):

$$PVPn = F.V + M.\omega \tag{1}$$

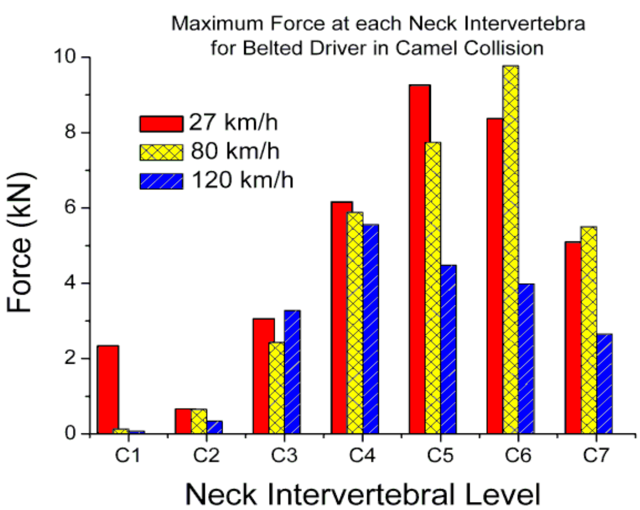
Where F is the resultant force (N), V is the resultant linear velocity (m/s), M is the bending moment (Nm), and ω is the angular velocity (rad/s). Eq. (1) represents the power obtained in transitional and rotational motions at each intervertebral level. The severity of neck injury in camel collisions was estimated based on the curves developed in Figure 1 (Al-Shammari, 2011).

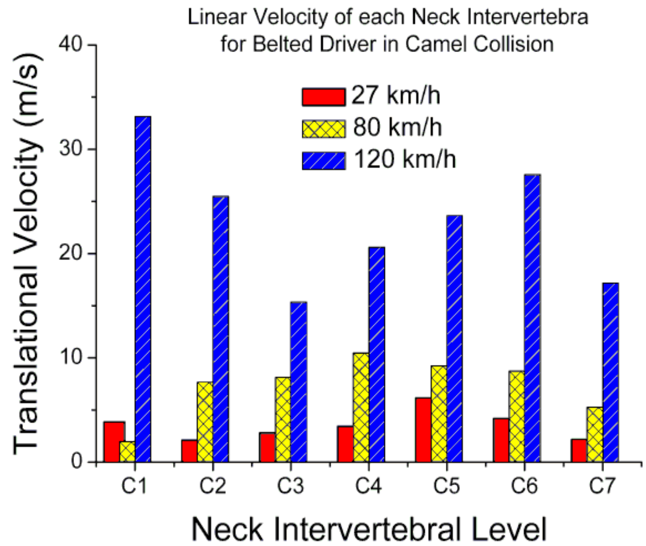
The risk of neck injury depends upon the change of speed (ΔV) during the impact. As the speed of the vehicle increases, the chance of getting severe neck injuries also increases (Smith et al., 2005). The current simulations also reinforce the fact that the risk of neck injuries in camel crashes is greater at higher speeds. Also, seat belts are seen to be effective in reducing the risk of neck injury. Table 5 shows the change in velocity (ΔV) computed from the simulations, and corresponding expected MAIS values of neck injuries. Table 5 corroborates that the severity likelihood of neck injuries increases with speed.

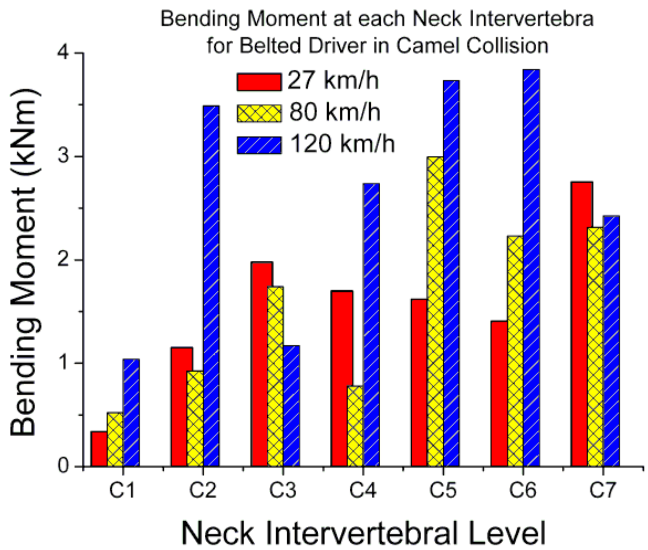
Table 5: Risk of neck injuries in the study

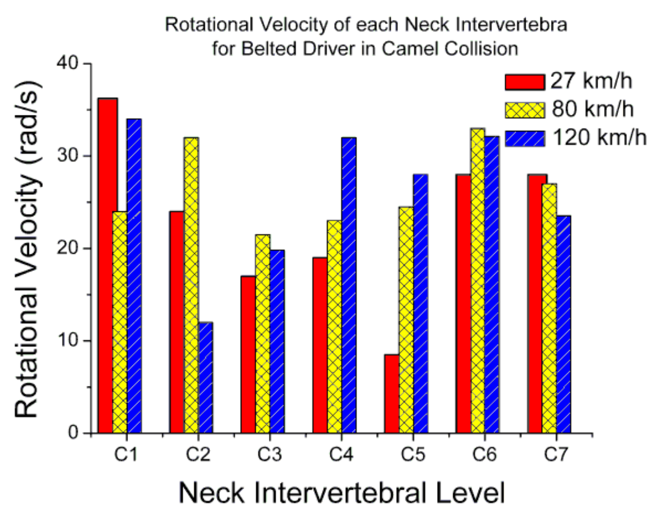
Impact Speed (km/h)	ΔV (km/h)	MAIS
27	25.11	2
80	36.37	4
120	55.83	6

Figure 8 shows the PVPn calculations for camel collisions at various impact speeds using the typical passenger car model in this study. The results are only presented for the cervical spine, since that is the most important region considered in the spinal injuries. In this figure, the first four graphs show force, linear velocity, bending moment and angular velocity of each vertebra. The fifth graph shows the PVPn calculated. The last graph shows the incidence of neck injuries at each intervertebral level obtained from field survey of real world crashes in the same orientation (Al-Shammari, 2011). A comparison of the last two graphs in **Figure 8** gives a quantitative comparison between the PVPn and the injury likelihood. From the comparison it can be seen that whenever the PVPn is high, the neck injuries increase. The statistical analysis shows that there is a highly significant correlation ($\chi2=26$, d.f=18, P=0.32) between the PVPn and the likelihood of neck injury at a particular intervertebral level for the different impacts in the study.









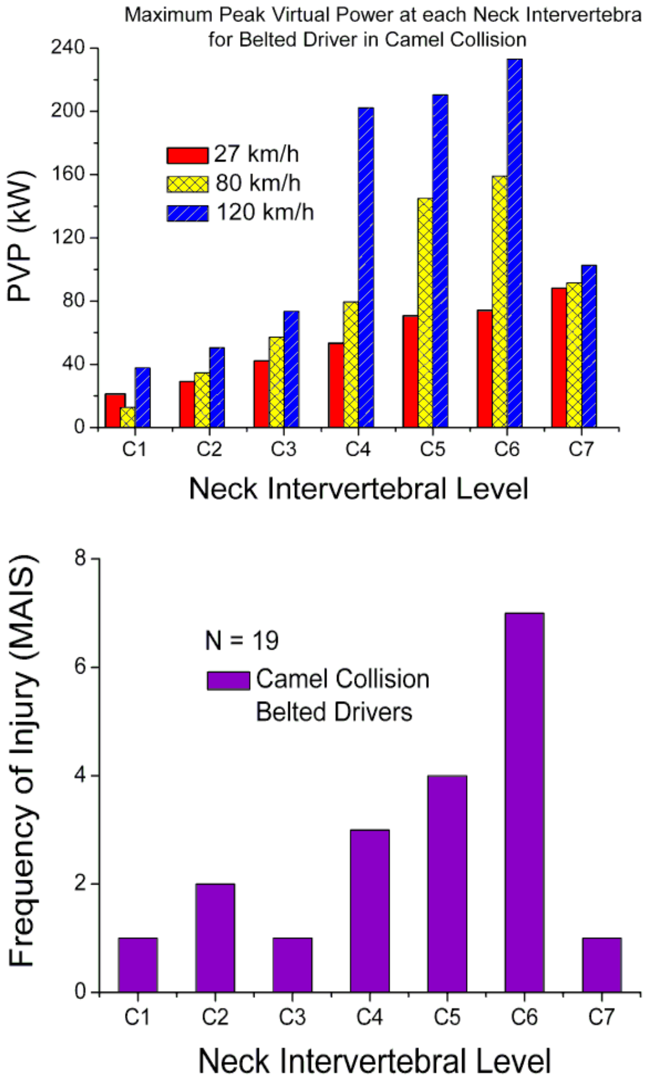


Figure 8: PVP for belted driver in camel collisions

The previous results of the PVPn scores obtained by simulations using a typical passenger car model indicate the neck injury severity well. Besides, based on the "Master PVP Curve" where the MAIS is linearly proportional to PVP, (Sturgess, 2002) the MAIS of the occupant can be depicted as shown in Figure 9. The MAIS results achieved from the "Master PVP Curve" indicates the neck injury severity well which shows the PVP is a good indicator of the occupant neck injury.

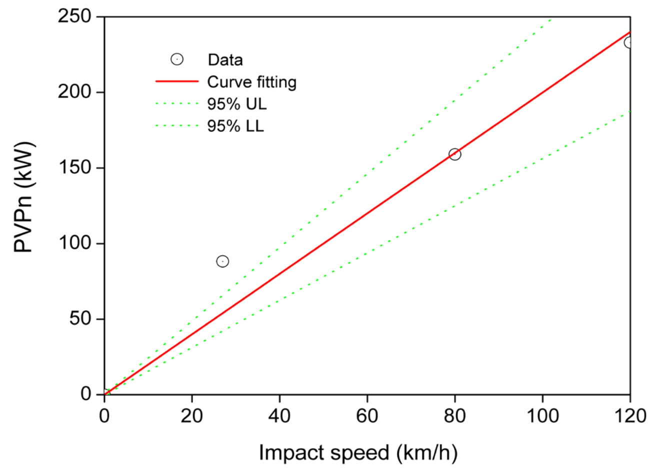


Figure 9: The Correlation between PVPn and impact speed for belted drivers in camel collisions

Camel Vehicle Collisions (CVCs) in Saudi Arabia are a leading cause of death and disability. CVC is a unique problem for this country. Despite that CVCs constitute only 1% of all RTAs in Saudi Arabia, these accidents represent 15% of the RTAs causing SCI and third of cervical injuries (AboAbat, 1999). The epidemiological studies of CVCs showed that the most spine regions injured in the camel collisions are the cervical and thoracic of vertebral column (Al-Shammari, 2011). In spite of that the number of CVC cases reported is less (2%) but all the cases resulted either in critical injury (AIS 5) or in fatal injury (AIS 6).

In this study, modelling of a typical CVC has been created in the sagittal and frontal planes to identify the common mechanisms of spinal injuries to drivers. An analysis of occupant kinematics, and the risk of neck injuries during CVC has been presented.

For the vehicle occupant, comparison of injury indices for belted and unbelted occupants indicates that the use of the seat belt is effective in reducing the injury likelihood in most cases.

The injury indices are also observed to increase with speed. Several studies have shown that the neck injury risk is associated with seat-belt use (Allen et al., 1982, Jonsson et al., 1991, Krafft et al., 1997 and Kullgren et al., 2000).

The results presented in this paper also show that the greatest forces occur on the lower cervical levels, giving a greater risk of disk and ligamentous injuries at the C4-C5 and C5-C6 levels in camel crashes. The mechanism of injuries in CVC's has a high potential for producing cervical spine injuries. The most common spinal injuries associated with CVC involve hyperextension of the neck, causing anterior ligament and disc damage. Additionally, the occupants of the vehicle usually assume a protective posture to avoid injury, flexing their necks and, if unrestrained, bending forward, and so the injury is to the occipital and cervical spine dorsally. If the occupant is restrained, vertical compression to the neck results in compression fractures, or a direct hit to the face results in an extension injury. If the person protects themself by lying sidewards on the seat, a multitude of force factors acting on the spine create a fracture pattern, consistent with flexion, extension, rotational or horizontal compression injury. Axial compression seems to be the most common mechanism of injury, which causes bony fragments to be pushed into the spinal canal; the presenting neurologic defect may be a burst fracture with loss of consciousness and complete quadriplegia.

The shape of the camel›s body contributes to the severity of the injuries. The centre of gravity of the camel is high, due its long legs, and the body readily hits the passenger compartment of the car. In a typical CVC, as the vehicle strikes the camel, its heavy weight (≈ 600 kg) falls on the front and top of the car. The roof is therefore pressed backwards, and down, and the windshield is inclined at a sharp angle. With the excessive forces acted by the camel on the vehicle structure, the front A-pillars at the sides of the windshield are bent rearwards and downwards towards the front seat occupant. The likely occupant kinematics in CVC suggests that the head of the occupant is contacted the A-pillar which might cause a head injury. This may have to be further confounded by a direct contact with the camel›s body. The fracture injury to the lower cervical vertebra is likely to have occurred as a result of forced flexion of the cervical spine due to head contact with the A-pillar, while the torso was continuing some forward and upward movement. This mechanism is supported by the evidence that the occupant was trying to avoid the camel crashing into the car by bending his neck forward. The intruding instrument panel supported by the camel›s body is the cause of injury to the thorax and thoracic spine.

PVPn has also been computed at each intervetbral level. It is observed that PVPn at each intervertebral level correlates well with the likelihood of injuries in camel collisions. This indicates that PVPn could be a good measure to predict injuries at specific inter-vertebral levels. Results also show that in a camel impact at a velocity above 80 km/h the passenger's chances to survive decrease rapidly, due to high accelerations, forces and PVPn. These results are also in consonance with crash trends reported in literature (Gens, 2001).

Conclusions

This study has presented how simulations can be used to understand the occurrence of neck injuries in camel collisions. It can be seen that these computational simulations of crashes provide a very powerful tool for understanding the dynamics of crashes and the risk of neck injuries.
Simulations in this work have been done in a 2D environment. Although, the 2D models provide a good indication for the use of PVPn as an injury predictor, this work can further be extended to 3D models. Detailed 3D finite element models would in principle be able to better predict the outcome in the crash. Further, while the computational models developed have been validated using available crash data, it must be pointed out that in the available experimental data the details of the tests are often not available. Appropriate testing facilities (full scale as well as Camel Crash Test) should be setup in Saudi Arabia for testing vehicles and their parts.

The current work has demonstrated the capability of the software tools in understanding the crashes as well as the kinematics and injury mechanisms in came; collisions. Some of the main limitations highlighted in the development of these simulation models are the availability of vehicle data, availability of human dummy models, and availability of data for validation and estimation of injury indices in an attempt to estimate the likelihood of injuries. These simulations can however be strengthened to study the injury mechanisms of other body parts as well as other safety issues.

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