ORIGINAL ARTICLE

Risk of cervical injuries in mixed martial arts

T Kochhar, D L Back, B Mann, J Skinner

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See end of article for authors' affiliations

Correspondence to:
MrKochhar, Royal National Orthopaedic Hospital, 82 Waverley Road, Enfield, London EN2 7AQ, UK; tonykochhar@hotmail.com

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Background: Mixed martial arts have rapidly succeeded boxing as the world's most popular full contact sport, and the incidence of injury is recognised to be high.
Objective: To assess qualitatively and quantitatively the potential risk for participants to sustain cervical spine and associated soft tissue injuries.
Methods: Four commonly performed manoeuvres with possible risks to the cervical spine were analysed with respect to their kinematics, and biomechanical models were constructed.
Results: Motion analysis of two manoeuvres revealed strong correlations with rear end motor vehicle impact injuries, and kinematics of the remaining two suggested a strong risk of injury. Mathematical models of the biomechanics showed that the forces involved are of the same order as those involved in whiplash injuries and of the same magnitude as compression injuries of the cervical spine.
Conclusions: This study shows that there is a significant risk of whiplash injuries in this sport, and there are no safety regulations to address these concerns.

Martial arts have been practised for many centuries. Some of the first ever descriptions of martial arts come from the time of Alexander the Great circa 325 BC. One of the first sports in the Ancient Olympics, the Ancient Greek form of martial arts, was pankration. Borne out of unarmed combat on the battlefield, martial arts have become an extremely popular sport. Each region of the world has its own historical martial art, with its own primary ethos and principle goals (table 1).

Over the past 100 years, masters of multiple martial arts have realised that no one martial art is superior and that a fusion of techniques makes the student more versatile and effective. From this experience was born mixed martial arts.

With respect to the United Kingdom, the first official tournament sanctioned by the governing body, the Ultimate Fighting Committee, was held at the end of 2002. Currently, there are over 300 mixed martial arts clubs listed on the British website.

Most bouts are usually decided by submission or knockout. A knockout in mixed martial arts is defined as being rendered unconscious rather than unable to proceed. It is obvious that there is enormous potential for sportsmen in this field to sustain severe and potentially fatal injuries.

This study aims to assess qualitatively and quantitatively the potential risk for participants to sustain cervical spine and associated soft tissue injuries.[1–3]

Four common techniques have been chosen. These were chosen, as their basic kinematics suggested that they would be most likely to result in cervical injury.

The four manoeuvres chosen are forms of takedowns. A takedown is a manoeuvre performed by a fighter to put the opponent on the floor, with the fighter usually on top of the opponent. The four are:

1. O goshi (judo). In English, it means "hip toss." The fighter and the opponent face each other. The fighter steps into the clinch and, using his shoulders, swings the opponent over his hips. The opponent is driven on to his back. It is a simple and common manoeuvre.
2. The suplex (jujitsu). The fighter grabs his opponent around his waist, lifts him up over his shoulder. As their combined centre of gravity moves, the fighter falls backwards on to his back, maintaining his hold on his opponent, who falls forward, on to his face.
3. The souplesse (a variant of the suplex). The fighter lifts his opponent from the waist, and swings him over his shoulder. At the last moment, the opponent is rotated over his upper chest and slammed down on to his back.
4. The guillotine drop (a choke hold). The fighter reaches around the back of the opponent's neck with one hand and completes the choke with the other hand. With the choke complete, the fighter falls backwards, raising the opponent off of his feet, flexing the opponent's neck and forcing him to the floor. The fighter drives backwards, tightening the choke.

Each of these manoeuvres uses the weight of the fighter and his opponent to force the opponent on to the ground.

The aims of this study were to:

- qualitatively and quantitatively analyse the kinematics of the four manoeuvres related to the performance of and training of mixed martial arts
- assess the biomechanical forces in the region of the head neck complex on the point of impact
- perform a motion analysis to compare the four manoeuvres with the results of impact tests, in the literature
- draw parallels between the kinematics of the two groups, thus identifying potentially dangerous motion in the manoeuvres[4–19]
- take quantitative measurements of the impacts and construct biomechanical models to be compared with the literature.[12–18 20–32]

MATERIALS AND METHODS

The motion during the techniques was recorded by two Sony (DV470 and 478T) digital video camcorders, one filming the general motion of the fighter and the opponent, and one focusing on the cervical region as the opponent hit the floor to assess cervical and head motion. Video stills were taken to form a series of the motion at impact showing the basic kinematics of each impact. The cameras took images at a frequency of 40 and 50 frames/second. The motion of the head and neck was then qualitatively assessed.

Two experienced practicing martial artists took part in the video analysis. The fighter (performing the takedowns) was 33 years old, 170 cm tall, and weighed 80 kg. The opponent (being taken down) was 27 years old, 180 cm tall, and weighed 93 kg.

Table 1 Brief descriptions of the main regional forms of martial arts, including their country of origin and ethos

Name	Description
Brancaille	French: wrestling contest
Capoeria	Native Brazilian dance/martial art
Dim mak	Oriental: death touch, striking pressure points
Judo	Japanese: grappling, throws, strikes
Jujitsu	>750 styles in Japan
Karate	Japanese: strikes, kicks, punches
Kenpo	First American: strikes to vital areas
Kung fu	Chinese: range of techniques
Pencak silat	Indonesian: attacks legs
Pit fighting	American: street fighting/brawling
Sambo	Russian: grappling, submission techniques
Savate	French: kickboxing without knee strikes
Shootfighting	American: derived from vale tudo
Tae kwon do	Korean: ''art of kicking and punching''
Vale tudo	Brazilian: ''anything goes''

Each technique was performed a total of 10 times, each after a period of rest. This was for three main reasons. The first was to confirm that the kinematics of each manoeuvre was similar in each video analysis. The second was to measure the height from which the opponent was driven down on to the ground; an average height was taken. These measurements were calculated by analysing the film and marking reference points on the video stills of the height to which the opponent's centre of gravity was raised. Reference marks were placed on the opponent's anterior superior iliac spine, on the side of the fighter's clothing, and on the wall on the other side from which the reference filming was taken. The centre of gravity was assumed to be slightly superior to the coordinate reference origin, namely at the level of the anterior superior iliac spine of the pelvis (but in the coronal and sagittal midline). The point of initial impact was also assessed from the video footage and noted. Finally, the position of the head, relative to the thorax, at impact and the end of motion was measured. This was done by comparing the video stills with standardised pictures, taken before the experiment, on a computer.

The third was to measure the time taken from the top of the takedown, when the fighter began driving the opponent down, to the point of impact; an average time was taken. This measurement was calculated using a digital stopwatch and the video footage, with the knowledge of the frequency of image capture of the camera.

These values were taken to construct mathematical models to help to correlate the manoeuvres with the biomechanical information present in the current literature.

RESULTS

Kinematic analysis of the four manoeuvres

O goshi: the hip throw

The fighter's body was raised and driven down on to the ground from an average height of 115 cm. The average time for the takedown was 0.29 second.

From the video, the first point of impact was at T2/T3 in the midline (9/10 manoeuvres.) At the point of impact, the cervical region was slightly flexed, with the head in forward translation of a mean of 4–5 cm (when compared with standard reference pictures of the fighter's resting positions). On impact, the body came to rest rapidly, but the unrestrained head and neck were still subject to the driving acceleration. The head then moved backwards with associated cervical hyperextension, until the occiput impacted on the ground. Mean posterior translation was 6.2 cm, from its resting position, before the occiput hit the ground. There was then a forward motion of the head with cervical spine flexion. The impact finished with the head in the starting position of anterior translation of about 4–5 cm.

The motion from impact to rest of the head and the cervical region suggests forced displacement of the head until it hits the ground and then forward flexion until rest.

The suplex

Problems were encountered in the video analysis of this manoeuvre. During the practice run, the opponent sustained an injury to his anterior cervical region and was unable to proceed. No other volunteer was happy to participate in the suplex, not even the first author! Analysis of this manoeuvre was abandoned.

The opponent was cleared of any serious cervical injury by his regular practitioner and had fully recovered within a week.

The video analysis taken from the single run through of this manoeuvre revealed a height of 155 cm. The time taken from the initiation of driving the opponent down to impact was 0.32 second. From the video analysis it can be seen that the initial point of impact was the mandibular symphyseal region. There was then continued and sustained posterior translation of the head with associated cervical hyperextension until the end when the opponent came to rest and began to complain of pain. A significant part of this hyperextension seemed to be from the atlanto-occipital segment.

The posterior translation of the head was measured at about 9 cm. Surprisingly there was no axial rotation—that is, the opponent did not twist his head away from the full frontal impact upon the ground.

Although this part of the experiment was not completed, it proved enlightening and informative to all participants.

The souplesse

The mean height from which the opponent's assumed centre of gravity was 142 cm. The mean time taken for this part of the manoeuvre was 0.31 second.

The initial point of impact was the T2/T3 region, (8/10) in the midline. The head was measured at a position of positive anterior translation of 4 cm. Once the thorax and body came to rest on impact, the unrestrained head once again moved back with associated cervical hyperextension until the occiput hit the ground, the head being displaced 6.7 cm behind its resting position.

From this impact of the head, the head moved anteriorly, beyond its starting position, but within normal limits of

Table 2 Summary of biomechanical and kinematic model equations

Manoeuvre	Driving acceleration (m/s^2)	Force on point of impact (N)	Energy transfer (J)	Driving force on head (N)
O goshi	27.3	2566.2	2951	178.3
Suplex	30.3	2848.2	4414.7	197.9
Souplesse	29.8	2801.2	3977.7	194.6
Guillotine drop	13.1	1231.4	1354.5	85.5

movement—that is, the chin did not touch the anterior chest wall. This motion was very fast, and we were unable to collect valid measurements because of the limitations of our equipment. The impact finished with the head coming to rest in the neutral position.

The guillotine drop

The fighter began to drive the opponent down from an average height of 110 cm. This was not a throw, and so the opponent's total body weight was not involved. The time taken to drive the opponent down had a mean value of 0.41 second. It proved to be difficult to analyse the video. This was due to the nature of the manoeuvre, in that the choke hold of the fighter masked the neck movements. However, it seems that the choke forces the opponent into a position where the neck is flexed. As the opponent falls to the ground, flexion is increased, with a probable increase at the atlanto-occipital motion segment. The initial point of impact seemed to be at the level of the xiphisternum (T9). As the fighter drives back, the opponent's neck is flexed forward once again in a rapid fashion (the video imaging was too slow to calculate this time). It seems that this manoeuvre causes strong flexion forces on the cervical spine and its junction with the occiput.

Values were calculated and compared with those found in the literature for scenarios with similar kinematics and known associated cervical injuries. For these calculations some assumptions were made:

- The centre of gravity was positioned at the level of the anterior superior iliac spines, midline in coronal and sagittal planes.
- There was a constant driving acceleration. This is in keeping with the description of the classical technique in each manoeuvre.
- The motion and forces acted in the same sagittal plane from initiation to impact of the manoeuvre.
- The neck flexors have sufficient reaction time to resist the posterior translation of the head. The literature suggests that in rear end impacts, the sternocleidomastoid muscles cannot react quick enough to oppose the hyperextension (reaction time is quoted as being 100–150 milliseconds), and once in hyperextension they have minimal power.
- The weight of the opponent's head was 6.5 kg and the weight of the neck made no contribution to the driving force of the head after impact. This value was calculated as 6.95% of the total body weight as suggested in the literature.

It should also be noted that the mathematical models have been constructed with a view to posterior linear motion of the head. Clearly, the motion of the functional spinal units (and thus the general motion of the cervical spine) involves angular motion. The motion of the head-neck complex receives a significant contribution from the atlanto-axial complex in the way of angular motion in the sagittal plane. However, most studies have presented their results with respect to the linear motion of the head. For our study to be comparable with the published literature, the authors have constructed the experiment and models in a similar fashion.

Mathematical models

To assess the biomechanical forces, we need to find the acceleration from the fighter driving the opponent to the ground. From the equation

$S = ut + \frac{1}{2}at^2$ for the manoeuvre

where S is the distance of the opponent's centre of gravity before being driven down to the ground, t is the time for the opponent to be driven to the ground, a is the driving acceleration, and u is the initial velocity (for this scenario it is equal to zero), we can calculate the force of the impact on the opponent's upper back.

Using Newton's second law of motion and assuming a constant acceleration throughout the fall,

$$F = ma$$

where F is the driving force of the impact on the opponent as he lands (N) and m is the mass of the opponent (kg), and assuming that the opponent's head weighs 6.53 kg, we can calculate the driving force of the head backwards after impact.

The other value required is the transfer of energy from the opponent being driven into the ground. When the opponent is at the top of the manoeuvre, before he falls to the mat, he has potential energy. The equation for potential energy measured in joules (PE) is as follows:

$$PE = mah$$

where h is the distance of travel—that is, from the top of the manoeuvre to impact (cm).

By using the motion equation

$$v^2 = u^2 + 2as$$

we can calculate the velocity of the body at impact (v is the final velocity at impact).

Table 2 summarises the results.

Comparison of manoeuvres with evidence from the literature

To confirm or reject the possibility of cervical injury, these variables were compared with similar incidences from the published literature shown to produce cervical neck injuries.[13–18]

The kinematics of the o goshi and souplesse from the point of impact bear a considerable resemblance to the kinematics of a rear end motor vehicle collision. With respect to car collisions, it has been shown that the biomechanics, kinetics, and kinematics all contribute towards the outcome. It can be seen that the impact with the opponent on the ground can be directly correlated with the moment of impact in a rear end collision. If one compares the force imparted on the driver from the seat with the reaction force of the ground on the opponent, one can see that they act at similar sites and in similar directions. There is also similar posterior translation of the head after impact in both our studied manoeuvres and the car impact models. We cannot prove from this study that the cervical motion after impact in the o goshi and souplesse has the biphasic S shaped kinematics as described by Panjabi *et al.*[10] However, the action of the force causing this motion is of similar magnitude in the two scenarios and the gross pattern of motion is comparable.

The authors strongly believe that, as the gross kinematics and action of the driving forces are comparable in these scenarios to the biphasic whiplash motion scenario, then injury will similarly occur in martial arts. As the magnitude of the force is of the same order, we conclude that it is likely that the biphasic motion of whiplash does occur in the hip throw and souplesse after impact of the body.

We calculated the kinetic energy (KE) created by the impact for these two manoeuvres:

$$KE = \frac{1}{2} mv^2$$

We find that the kinetic energy imparted to the subjects was

$$KE = \frac{1}{2} \times 450 \times (2)^2 = 900 \text{ J}$$

With respect to the o goshi and souplesse, the corresponding values for the kinetic energy transmitted by the impact can be similarly calculated:

$$KE_{ogoshi} = \frac{1}{2} \times 94 \times (7.92)^2 = 2948 \text{ J}$$

$$KE_{souplesse} = \frac{1}{2} \times 94 \times (9.2)^2 = 3978 \text{ J}$$

This shows that the kinetic energy associated with these manoeuvres exceeds the threshold limit to create whiplash motion. If the statement that energy transmission plays a role

What is already known on this topic

There is minimal information in the literature documenting the mechanisms of cervical neck injuries in martial arts. The mechanisms of the injuries and forces required have not been clearly analysed, yet the potential for major severely disabling injury is present.

What this study adds

This study shows clear similarities in the force, kinematics, and biomechanics required to produce cervical neck injuries in rear impact vehicle accidents and these four common martial arts manoeuvres. It shows that significant forces are applied to this region, and injuries may be more severe than realised.

in injury, this comparison supports the theory that the manoeuvres reproduce the motion and have a significant risk of injury. However, the role that energy transmission plays in injury has not been assessed in the literature reviewed. With respect to the two other manoeuvres (suplex and guillotine drop), no studies were found in the literature with which to compare the kinetics.

CONCLUSIONS

These four common mixed martial arts manoeuvres have kinematics that can result in serious cervical injury.[33–43] Strong parallels can be drawn between the kinematics of rear end motor vehicle impacts and the described motion of the o goshi and souplesse.[10–18 44] The gross motion of the head-neck complex in these two manoeuvres and rear end motor vehicle impacts is similar, including the mechanical obstruction from hyperextension of the cervical region by the floor and the car seat headrest respectively. The suplex exhibits significant risk of hyperextension injury. The guillotine drop kinematics reflect mechanisms of cervical neck flexion injuries. It should be noted that enactment of the correctly applied suplex in our experiment did result in cervical injury, albeit mild.

Comparison of our biomechanical models with road trauma research has revealed comparable forces to produce cervical injury.[10–18 44] It should be noted that we have studied the performance of classical movements by experienced practitioners. These are not the movements that a less experienced practitioner would consistently produce, and deviations may produce even larger forces.

This study has clearly shown that there is a risk of cervical injury from these four manoeuvres used in martial arts.

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Authors' affiliations

T Kochhar, D L Back, B Mann, J Skinner, Royal National Orthopaedic Hospital, Stanmore, Middlesex, UK

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