

Review

The Analysis of the Cause-Effect Relation between Tractor Overturns and Traumatic Lesions Suffered by Drivers and Passengers: A Crucial Step in the Reconstruction of Accident Dynamics and the Improvement of Prevention

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Abstract: The evaluation of the dynamics of accidents involving the overturning of farm tractors is difficult for both engineers and coroners. A clear reconstruction of the causes, vectorial forces, speed, acceleration, timing and direction of rear, front and side rollovers may be complicated by the complexity of the lesions, the absence of witnesses and the death of the operator, and sometimes also by multiple overturns. Careful analysis of the death scene, vehicle, traumatic lesions and their comparison with the mechanical structures of the vehicle and the morphology of the terrain, should help experts to reconstruct the dynamics of accidents and may help in the design of new preventive equipment and procedures.

Keywords: farm tractor; occupational accidents; prevention

1. Introduction

Farm tractors are heavy, large, powerful vehicles. If they are used (a) without the right safety equipment as Roll Over Protective Structures (ROPS), seat belts, helmets, crush proof walls of cabs, (b) without a correct evaluation of operational risks (mechanical peculiarities of the vehicle, unstable terrain, towing an excessive load, driving on sloping and irregular or slippery ground where there is a low coefficient of traction) or (c) when the overturn angle is exceeded, they may overturn and throw the occupant(s) onto the ground and crush them [1–8].

The influence of engineering research and techniques on the construction of farm tractors has, in recent years, been seen mainly in the development of and improvements to ROPS, on the morphology and protection of the Deflection Limiting Volume (DLV), and on safety equipment such as seat belts, helmets, crush-proof cab walls and safety shields for the power take-off (PTO) but nearly 50% of fatal farm accidents still involve tractors, while a significant number of rollovers (50–60%) result in the death of the drivers or passengers [1–5].

Etherthon et al. reported that 59% of tractor-related fatalities occur in agriculture, forestry and fishing, with the remaining cases occurring in the manufacturing, services and construction sectors [1].

A variety of agricultural activities have been identified by the US Government Centers for Disease Control and Prevention as being frequently associated with tractor rollovers. These include using rotary mowers (32%), transporting equipment or farm products (21%), checking livestock or property (14%), hauling logs (11%) and planting, ploughing or cutting hay (11%) [9].

Pickett et al. also looked at the incidence of fatal injuries in work-related farming accidents and found that 9.6% of deaths occurred because of sideways overturns and 6.4% in rear or front overturns [3].

The Directives of the European Community and the Organization for Economic Co-operation and Development (OECD) are constantly striving to improve the technical manufacturing parameters and research procedures to analyze the ability of vehicles to withstand impacts and crushing and to devise new regulations which aim to prevent overturning, to guarantee the solidity of cabins and to preserve the DLV: types approvals refer to each category of tractor and involve specific variants as the number of powered axles, steered axles, and braked axles, ROPS and preservation of the DLV [7,10,11].

However, despite ongoing engineering research, there are still no exhaustive analytical procedures or new investigative methodologies which might enable us to evaluate and thus prevent injuries or fatalities to operators and passengers when tractors overturn.

The analytical procedures normally used by coroners and forensic pathologists to describe the morphology and the anatomical location of traumatic lesions and to correlate them with the causative vectorial forces acting on the human body during accidents, appear to be useful for agricultural engineers in order to clarify the dynamics of tractor overturns and to plan preventive devices and operative procedures [12].

2. Tractor Overturn Risk Factors

The main reasons why tractors overturn, are:

1. Human behavioral factors in which tractor drivers:

- (a) ignore or fail to observe correct standards of conduct when behind the wheel
- (b) corner abruptly and at speed
- (c) are working alone for long periods, in adverse environmental and weather conditions, in isolated, rural areas (82% on farms and only 18% on public roads, as reported by the US Centers for Disease Control and Prevention) where it may be extremely difficult to get rapid access to emergency services and medical aid; such work may also be performed at night without an efficient lighting system [9,12].
- (d) may have been drinking or taken drugs, thus affecting reaction times
- (e) may be elderly and have cardiovascular or neurological issues which dangerously affect reaction times and the ability to recover from trauma

2. Factors involving ground and weather conditions:

When maneuvering the tractor on a slope at more than the α overturn angle, side, rear or front rollover will result (the α overturn angle and the % gradient of the slope are represented mathematically by the following equation: $i = a_t/2 h\alpha$, where i is the percentage gradient, a_t is the tractor's wheel track, h is the height of the center of gravity, and α the angle between the incline and the horizontal ground line) [12–18].

In wet or icy conditions:

- (a) the ground can become slippery with the tractor operating in conditions where there is a dangerous coefficient of traction which leads to side, rear or front overturns (The coefficient of traction between two surfaces, e.g., rubber tyre and ground surface, is expressed by the following equation: $A_f = C_a \times C_f$, where A_f is the frictional force which resists the relative motion between two surfaces (tyre and ground), C_a is the coefficient of traction between

those two surfaces, and C_f is the compression force involving two opposing surfaces (i.e., the weight bearing upon the wheel)) [18].

- (b) verges, escarpments and the banks of waterways may become waterlogged and give way.
3. Factors involving the technical or functional characteristics of tractors: farm tractors have a high center of gravity and/or a narrow axle track; they may be rather old and not equipped with adequate or upgraded safety systems; they may also be poorly maintained and have the wrong tyre pressures.
 4. Factors due to the behavior of machinery and equipment towed by a tractor and coupled to the PTO:
 - (a) excessive loads towed by a tractor.
 - (b) excessive loads may be towed by a tractor and coupled to a functioning PTO; in both cases the operator may fail to consider the fact that the PTO coupling and the heavy load will cause the vehicle to behave differently when, for example, cornering or traversing a slope.

Besides human, technical, environmental and weather risk factors there are other critical risk factors which may increase the number of injuries and fatalities: adults and minors transported as passengers (Purschwitz et al. reported that victims of tractor rollovers range in age from less than 1 year to over 90) may be seated in inappropriate places on the vehicle and not be wearing seat belts or helmets; in these cases, tractor rollovers can result in very serious trauma and extensive crushing; obviously children, because they are physically smaller and have less resistant tissue, can suffer devastating trauma, with crushing, bone fractures, and severed limbs in various areas of the anatomy, with consequent polytraumatic shock [9,14].

Dogan et al. reported that tractor rollovers cause more fatalities among passengers, both adults and children, than among drivers: this is probably since adult drivers are afforded greater protection by the ROPS, and are physically more robust than children [12,15–17].

Even when the vehicle is equipped with ROPS, drivers can suffer fatal injuries because of tractor rollover, especially when they are not wearing a seat belts. Such injuries result from violent impact of the head, chest, spinal column or limbs against the internal surfaces of the cabin or the steering wheel, or may occur when external objects, rocks, branches or tree trunks penetrate the cabin safety zone (DLV) during or at the end of the overturn [2,7,10,12].

Researchers and engineers are currently trying to fully understand the dynamics of tractor overturns, which may involve different impact points on the body, and to explain the presence of lesions in different anatomical areas, to be able to identify critical safety issues. Unfortunately, experimental tests involving the use of dummies or prototypes still fail to properly explain the dynamics of an overturn, and the impact upon and deformations of the cabin and ROPS through the absorption of kinetic energy. As a result, the tests do not help us to understand how we can counteract the action of those vectorial forces responsible for driver injuries or death [18].

Over the last few decades manufacturers have tried to produce specific safety systems incorporating inclinometers or position-sensors to alert the driver to an increasing risk of rollover, and have connected such devices to recording devices, which function rather a like aircraft flight recorder. However, technical improvements still should be made to these instruments if they are to supply exhaustive data to researchers, engineers and manufacturers about the dynamics of tractor rollovers [18].

Coroners, forensic pathologists and agricultural engineers should work together closely not only to complete investigations required by the courts but also to support research on the dynamics of tractor overturns and the design of new vehicles, preventive equipment and operational guidelines: the knowledge of physical, mechanical and pathophysiological risk factors should be synergistically taken into account by technical and medico legal experts when investigating the consequences of tractor rollovers or researching preventive equipments or procedures.

3. Genesis of Traumatic Lesions Caused by Tractor Overturn

Morphological analysis of the lesions suffered by the victims and their compatibility with the mechanical structures of the tractor or with features of the terrain play a key role in the reconstruction of accidents. This procedure is normal practice for coroners but is rarely carried out by agricultural engineers [19–21].

Traumas or injuries caused by farm vehicles and equipment have specific and recognizable characteristics and can provide useful information not only for coroners but also for technicians, engineers, builders and researchers [19–21].

When part of a tractor strikes the human body, it produces macroscopic and microscopic modifications to both the superficial and deep tissue, depending on both the amount of energy absorbed and on the shape of the part or parts of the vehicle, ground, branches, rocks, etc., which are in contact with the driver's body. Obviously, the damage inflicted upon those tissue structures which absorb the energy is also determined by the resilience, elasticity and deformability of the tissue itself [19–21].

The same results are seen when the moving human body strikes a stationary or moving object.

The forces which act upon the human body are the same as those which acts on any physical structure (e.g., breaking or deforming parts of the vehicle, the ground or trees in the immediate area of the accident), and mainly involve mechanisms of compression, traction, bending and torsion.

The human body is equipped with various tissue components, each of which has specific characteristics of strength, elasticity and deformability and so the effect of damaging, external forces, whether single or multiple, opposed or synergetic, can generate widely varying traumatic results.

In the case of the compression and traction of human tissue, as with all other inanimate materials, the resulting deformation is expressed by the following equation: $E = \sigma / \varepsilon$ where:

E is Young's Modulus expressed in Newtons/surface area in m^2 of the body involved

$\sigma = \text{force/surface}$, is the ratio between the applied force and the surface area of the body involved, orthogonally to the force applied

$\varepsilon = \Delta l/l$ is the ratio between the length of the body after and before the load is applied.

Deformation caused by bending processes is expressed by the following equation:

$H = \sigma / \varepsilon$ where:

H is the Flexural Modulus expressed in Newtons/ surface area in m^2 of the body involved

$\sigma = \text{force/surface}$ is the ratio between the applied force and the surface area of the body involved

$\varepsilon = \Delta l$ is the amount of flexion.

The deformation produced by torsion is expressed by the following equation:

$K = \sigma / \theta$ where:

K is the Torsion Modulus expressed in Newtons/ surface area in m^2 of the body involved

$\sigma = \text{force momentum/surface}$ is the ratio between the applied force and the surface area of the body involved

$\theta = \Delta^\circ$ is the torsion angle.

Another important factor to consider is the length of time that the force (be it compression, traction, bending or torsion) is acting upon the body. These forces can be constant, increasing or decreasing, and release different amounts of energy [18–21].

4. Traumatic Injury Patterns Due to Tractor Overturn

The injuries resulting from tractor rollover which are of interest from a medico-legal and an engineering point of view, similarly to those caused by other vehicles, are well-known in forensic pathology and are usually revealed during the external examination of the body, and fall into the following categories:

- excoriation
- ecchymosis
- brush burn abrasions

- blistering
- tearing
- tearing and bruising
- cuts
- sharp injuries
- cuts and sharp injuries
- tissue loss.

These lesions are normally caused by impact with surfaces which have:

- flat surfaces [i.e., side walls of the cabin, mudguards, engine covers, as well as the ground (farmland, tracks or roads)].
- uneven surface which may be rounded, pointed, sharp or irregular (i.e., the ROPS, the steering wheel, uncovered parts of the engine, type tread, rocks, branches or tree-trunk slying on the ground) [12].

In addition to superficial lesions, serious deep bone fractures and organ ruptures may occur, owing to the significant amounts of energy they have absorbed.

According to where they are located, characteristic morphological features may be observed: wounds near broken-off bone stumps which look like cuts because the bone slices through the skin (as well as the muscles, blood vessels and nerves) from the inside and tend to produce wounds with neat edges [12,16,17].

Bone tissue offers poor resistance to torsion, traction and bending, but copes better with compression; fractures can be caused by means of a mechanism of direct absorption of an external force or by transmission of an external force absorbed in a specific area of the skeletal structure distant from the point of fracture (for example, the fracture high on the femur, at pelvis level, due to impact with the foot, lower leg or knee). The skull is of interest and importance here: cranial fractures can be caused by impact with large flat surfaces (the most common scenario is that of a fall) or impact with edges which may be rounded, sharp, pointed, or irregular (parts of the tractor, rocks, stones, branches or tree trunks).

While different areas of the cranium vary in thickness and strength, it has been estimated that the cranial vault can withstand deflections of several millimeters without fracturing. Impact with flat surfaces can cause linear fractures of the skullcap which radiate out from the point of impact (caused by the bending first of the inner and then the outer cranial tables) and circular fractures (caused by the bending first of the outer and then the inner cranial layers). In the case of uneven surfaces, the fracture may be depressed, with the size and shape corresponding to the impacting object or structure [12,16,19–21].

The rupture of internal organs is more frequent in cases of massive trauma, when the forces acting upon the body are single or multiple and synergetic but of high intensity, as is the case with violent impact, crushing, traction or fragmentation [12,16,19–21].

The internal organs also have specific characteristics of resistance, elasticity and shock absorption, while the solid and hollow organs behave differently.

The mechanisms involved may be direct or indirect: the transmission of the force, the acceleration and deceleration produced by the impact can cause the detachment of muscles, tendons and vascular peduncles of organs [12,16,19–21].

The typologies of fatal injury which can occur because of farm tractor rollovers, may involve the driver or passengers being:

- thrown to the ground and crushed by the vehicle with lethal injuries to the chest, head or limbs
- thrown to the ground and suffering serious or fatal injuries due to the fall and collision with rocks, tree trunks, branches or the ground/road

- thrown to the ground and crushed more than once by the machine in cases of multiple rollovers and then found fatally crushed at some distance from the machine
- thrown to the ground and crushed more than once by the tractor in the event of multiple rollovers, with the victim found crushed under the vehicle
- thrown to the ground and run over by the still moving tractor
- thrown into water (streams, irrigation channels, ponds, lakes, etc.), crushed and drowned
- entangled in and/or strangled by the moving tractor parts resulting in lethal mutilation (i.e., from the PTO or Power Take-Off)
- injured by foreign objects, such as rocks, branches or tree trunks penetrating the cabin safety zone during single or multiple rollovers
- burned after the contact with hot parts of the engine or the exhaust, or burned/carbonized after the vehicle caught fire [6,7,10,11,15,16,19,20,22–26].

5. Pathophysiology of Traumas Caused by Tractor Overturn

From the pathophysiological point of view Goodman et al. reported that fatalities due to tractor accidents may result in the chest being crushed (82.6%), exsanguination due to thoracic or extrathoracic lesions (4.4%), strangulation or asphyxia (4%) and drowning (3%) [20].

In rare cases of fire, the victims may display evidence of burning or carbonization, in addition to trauma injuries.

As reported by Bernhardt et al. the intensity of the vectorial forces acting upon the bodies of the driver or passengers in tractor rollover accidents is demonstrated by the fact that nearly three-fourths of the victims die in the first hour after the accidents while nearly 87% die within the first 24 h [12,20,27].

Moreover, as reported by Myers et al., the percentage of deaths resulting from side overturns in ROPS-equipped tractors is less than half those occurring when non ROPS-equipped tractors overturn (1.6% versus 3.7%) [7,20].

Similarly, Cole et al. reported that 1.12% of deaths involved ROPS-equipped tractor overturns (to the side, rear and front) as against 5.42% in tractors not equipped with ROPS [28].

Cole et al. also underlined that surviving victims of rollover accidents may suffer temporary disability in 13.5% and permanent disability in 3.16% of cases after accidents involving non-ROPS-equipped tractors [28].

In cases where the victim is crushed, either by the vehicle or other objects, if the weight is concentrated on the chest area, death is caused progressively by crush asphyxia, following compression of the rib cage and the arrest of respiratory movements and alveolar ventilation. In such cases, external post-mortem examination may reveal the “ecchymotic mask” phenomenon, characterized by conjunctival and facial petechiae, and intense purple congestion and swelling of the head, face, neck, upper chest and sometimes the upper limbs [16,29–32].

Petechiae may also be found in the oral mucosa while bulging of the eyeballs and epistaxis may also occur. The presence of cutaneous and mucous petechiae, purple congestion and swelling of the upper body is caused by: (a) an increase in venous capillary pressure owing to the reduced return flow to the right chambers of the heart (this increase is facilitated by the absence of valves in the main veins of the neck and head); (b) persistent arterial flow towards neck and head, c) the crush victim performing an involuntary Valsalva manoeuvre, which produces a further increase in intrathoracic pressure and a further reduction in the return flow to the left heart chambers [16,29–32].

Obviously, this compression of the chest does not only produce haemodynamic effects (increase in the peripheral venous pressure in the upper body, associated with the continued arterial blood flow towards the periphery) but also respiratory consequences, with hypoxaemia caused by the arresting of breathing movements and alveolar ventilation [18,21,31,33–37].

If the chest is immobilized but not crushed, the discoloration of the skin associated with crush asphyxia will be absent since there will be no increase in venous capillary pressure; but because the

breathing movements and alveolar ventilation will be obstructed, arterial hypoxaemia will occur and lead rapidly to death by cardiac arrest [18,29–31,33,34].

Another type of injury is that caused by the victim being trapped under the wheels of the still-moving tractor: significant lesions in the affected parts of the body, here we see serious damage to internal organs, bone fractures and severe surface wounds (lacerated and contused wounds, ecchymosis, patterned excoriations, tissue loss which may mirror the shape of tractor tyres or treads); such wounds are normally caused by the crushing action of a rubber tyre or continuous track [16,29–31].

It is also important to distinguish, during the post-mortem examination, between injuries caused when the body of the victim is thrown to the ground and those which follow in rapid succession when the victim, already on the ground, is crushed by part of the tractor: there will be superficial wounds caused by the impact with the ground (which may be flat or irregular with stones, rocks, branches or tree-trunks) and both superficial and deep wounds produced by crushing under the tractor and by contact with specific structural parts of the vehicle [12,16,29–31].

6. Morphology, Anatomical Location and Cause-Effect Relation of Traumatic Lesions Due to Tractor Overturn

The observation at post-mortem of the morphological characteristics, the topographic anatomy of the lesions caused by the rollover and the mechanisms by which they are produced, is an essential part of the analysis of the dynamics of accidents caused by tractors and agricultural machinery [12,18].

Depending on the vectorial forces involved and the shape of the vehicle and its component parts, the lesions may superficially have varying morphologies and be attributable to single or multiple points of impact (POI) with specific structural or mechanical parts of the vehicle [16,19–21].

Macroscopic impacts, both superficial and deep, against the structural and mechanical parts of the vehicle, and with the ground surface and foreign objects outside the vehicle, must always be identified, studied and interpreted during the post-mortem examination to understand accident dynamics [16,19–21].

In cases of impact (with or without dragging) or compression the following may be observed: patterned excoriations or ecchymosis, and wounds (lacerated, lacerated/contused, cuts and cuts/sharp injuries), or tissue loss corresponding to parts or surfaces of the vehicle in question, and these can be useful in reconstructing the dynamics of the accident. The shapes and patterns of the excoriation and ecchymosis can in any case point to contact with structural or mechanical parts of the tractor, be they large or small, and which are analogous to those produced trucks in road traffic accidents.

The coroner during the necroscopic examination, and the engineers during the technical examination of the vehicle, should always consider the fact that accidents caused by farm tractors overturning involve phenomenally high forces, rapid acceleration and significant mass so that the impact of singular or multiple vectorial actions on the body of victims is often devastating and with lethal consequences [18].

As reported by Goodman et al., such vectorial actions may cause, especially in cases where the victim's chest is crushed, a variety of traumatic lesions associated with thoracic immobilization and compression, such as fractured ribs (non-displaced fractures, compound fractures, flail chest with serious ventilatory and haemodynamic impairment), sternal and clavicular fractures, spinal and scapular fractures, bruising and detachment of large areas of tissue from the external surface of the chest [12,18,20].

Such injuries may also cause endothoracic, parenchymal and vascular lesions. Organs located inside the mediastinum may also be damaged. There may be various intrathoracic consequences such as lung collapse, haemopneumothorax, congestion, contusion or lacerations of lungs sometimes associated with subcutaneous emphysema [18,20].

Extrathoracic anatomical areas may also suffer crushing, such as the head, maxillo-facial structures, cervical or lumbar spinal cord, abdominal and pelvic structures and limbs, which lead to fatal traumatic and haemorrhagic shock; the loss of limbs may cause massive exanguination [3,20].

Dogan et al. reported a frequency of lethal lesions in different anatomical areas as follows: head (33%), chest (10.5%), abdomen (2.3%), the extremities (1.2%) [12].

Gassend et al. reported that, in cases of tractor rollovers, 43% of fatalities involved extrathoracic injuries and 21% involved a combination of head and pelvic traumas. Dogan et al. presented the following results for a variety of combined lesions:

- head and chest (16.3%)
- chest and abdomen (12.8%)
- head, chest and abdomen (9.3%)
- head, chest, abdomen and extremities (5.8%)
- chest, abdomen and extremities (2.3%)
- head, chest and extremities (1.2%)
- head and abdomen (1.2%)
- head, abdomen and extremities (1.2%)
- head and extremities (1.2%)
- abdomen and extremities (1.2%) [2,12].

The variability of the locations of single and combined lesions reported by Dogan et al. confirms that the dynamics of tractor rollovers involve a multiplicity of vectorial forces [12].

Rees also confirmed that the trunk (chest, spinal column and pelvis) is more likely to be injured than the head or extremities and reported that injuries due to tractor overturns may cause the death of the driver in one out of four cases [38].

These data were confirmed by Gassend et al. who reported that 81% of victims of a tractor overturn normally die at the scene of the accident, 8% on the way to hospital and 11% after reaching the hospital [2].

Ince et al. similarly reported a significant frequency (48.8%) of deaths at the scene of the accident or during transportation to hospital [39].

Furthermore, Cogbill et al. reported that in the event of multiple injuries involving different anatomical areas of the body, the sum of the frequencies of all cases involving the chest amounts to 40%. This is due to the large number of different lesions, both superficial and deep, which are caused when the structural parts of the machine hit the surface of the chest. The contour of the lesions, especially those seen on the chest, may match parts of the engine block, the edge of the rear tyre or the mudguard; the shape of the superficial lesions may also match an even ground surface or any stones, rocks, tree-trunks, branches lying upon the area where the victim falls, before being hit and crushed by the vehicle [12,40].

Therefore, a key part of the post-mortem examination performed by coroners is the identification, description and comparison of the impact points on the body with the ground, with the tractor's structure and mechanical parts. The presence of side, front or rear impact points on the body compatible with contact with the structure or parts of the vehicle is very important in the reconstruction of the tractor's direction of roll, i.e., to the side, forwards or backwards [18].

7. Medicolegal and Technical Implications

Coroners may be required to answer the courts' questions about the whole dynamic profile of the accident and its consequences to determine the circumstances of the accident, the traumatic lesions inflicted and the cause of death. Therefore, post-mortem investigations should aim to prove that a specific vehicle was involved in the accident, to explain why and how it overturned, and to evaluate the cause-effect relation between the dynamics of the overturn and the lethal injuries caused by the impact of structural or mechanical parts of the vehicle upon the victim's body.

The main task of coroners and medico-legal investigators in cases of farm tractor overturn is to ascertain the real occurrence of the accident and to demonstrate a mechanistic cause-effect relationship between the action of specific parts of the vehicle and the lesions observed.

To be sure that a death due to fatal traumatic injuries occurred after a tractor overturn, the following investigative steps are of crucial importance to integrate the necroscopic findings with what was observed at the scene of the accident:

- to interact with experts in the field of agricultural engineering to evaluate and discuss any technical and mechanical issues which may help to understand the dynamics of the event (single sideways rollover within 90°, single/multiple sideways rollover more than 90°, single or multiple rear or front rollovers).
- to evaluate the death scene, the structural, mechanical and technical features of the vehicle, its direction of travel before and during the accident, the gradient of the slope and the morphology of the ground, weather and light conditions at the time of the accident and the type of work being performed at the time and its setting, i.e., whether it is (a) agricultural or zootechnical work, in fields or wooded areas, involving pruning, or sawing tree-trunks and branches; (b) normal field work, cultivation of a vegetable garden or arable land; (c) maintenance work such as hedge and grass cutting on farms or in parks and gardens; or (d) processes such as harvesting, haymaking, pruning or irrigation;
- to verify whether certified ROPS were fitted, whether a helmet and seat belt was fitted and in use;
- to analyze whether the morphology and characteristics of the various lesions, both superficial and deep, and in any anatomical area of the corpse, match any specific parts of the machine, ground or objects external to the cabin [12];
- to search for all specific signs of crush asphyxia (distinguishing the distribution of post-mortem lividity from the position of the ecchymotic mask or any ecchymosis in other areas of the body) and all thoracic and extrathoracic traumatic lesions caused by the accident;
- to reconstruct the medical history of the deceased and his/her psycho-physical condition when of the accident;
- to analyze toxicological data for signs of alcohol or drug use;
- to exclude any causes of death other than the lesions produced during the rollover and evaluate the vitality of wounds present at the moment of death, in order to be sure that it was not a homicide made to look like an accident, nor was it a death from other causes not covered by insurance, that was made to look like a fatality caused by tractor rollover;
- to exclude any natural cause of death (i.e., stroke, cardiovascular acute pathologies) responsible for the loss of control of the vehicle and its rollover;
- ascertain how isolated the scene of the accident was, and investigate the involvement of the rescue services (when they were alerted, the distance covered, and the time of arrival at the scene);
- ascertain if the victim died when of the accident, on the way to hospital or after admission to hospital [18].

To summarize, coroners and agricultural engineers need to co-operate to provide, by means of the analysis of the traumatic lesions and the dynamics of farm tractor rollovers, not only technical responses to the questions put by the courts, but also information which may prove to be useful in drawing up preventive criteria and finding solutions which may help us to avoid or mitigate the consequences of the overturning of a farm tractor or other self-propelled farm machinery [18].

8. Concluding Remarks

The co-operation between coroners, forensic pathologists and agricultural engineers can generate innovative methodologies through specific observation and research projects:

- retrospective analysis and statistical description phases with analysis of (a) the level of preparedness and perception among farm tractor drivers of the risk of accidents, (b) the causal dynamics of serious and fatal accidents, including the analysis of fatal or disabling injuries and further work on the demographic characteristics and age of the drivers, on the type of work performed and the topography of the scene of the accident [24]
- experimental simulation phases, with the definition of test scenarios and their relative models (prototype-vehicles, dummies, etc.)
- final phases of proposals and solutions with the design of innovative tractors, equipment/devices and new models of driver behaviour [41].

There remain, however, the following problems regarding tractor rollovers, which demand innovative solutions:

- tractor drivers are often unaware of the risks of an accident while driving, and of the need to adhere to a code of conduct when driving and to use modern safety equipment [11,25];
- even when inside a ROPS-equipped cabin and when wearing seat belt and helmet, the driver can still suffer serious, and sometimes fatal, injury because of a single or multiple rollover beyond 90°, when foreign objects (rocks, branches, tree-trunks, etc.) penetrate the driver's safety zone or, in the event of a multiple rollover, if the ROPS collapses [11,25];
- during rapid acceleration and deceleration when the vehicle is rolling, even when the tractor is equipped with ROPS and the driver is wearing helmet and seat belt, serious trauma can occur, resulting in injuries to the head, chest, abdomen and limbs due to the body hitting the front, rear or side of the cabin interior or foreign objects which intrude into the Deflection Limiting Volume [11,12,25].

In view of the inability of current safety features to properly protect the driver within the DLV, innovative new systems and devices need to be designed and we would accordingly like to make the following recommendations:

- improve experimental observations regarding the dynamics of tractor rollovers and the genesis of the different injuries caused by such accidents (the mechanical characteristics of the vehicle, the kind of accident and its location, the typology and location of lesions, the relative final positions of the victim and the vehicle) [12];
- foster close cooperation between coroners and engineers;
- strive to develop new preventive devices, equipment and procedures (wrap-around seats which reduce lateral movement, compulsory fitting of audio alarms in the cabin, cushioning systems to offer greater protection to front and rear for the head, chest and pelvis, inclinometers which electronically control engine shutdown and braking systems);
- ensure that only properly trained people can drive tractors and other agricultural equipment;
- ensure that people with psychophysical impairments are not allowed to drive tractors and other agricultural equipment; this may include elderly, infirm or retired farmers or members of farming families; this issue is of particular importance nowadays when many countries in Europe are encouraging or forcing people to remain active and keep working longer, with the result that there tend now to be more people driving these vehicles in advanced age, and this may, in turn, increase the number of fatalities due to tractor rollovers [1,8,12,42–44].

We need to improve training and raise awareness among drivers regarding safe driving and the use of existing safety equipment, but at the same time work with industry to promote research into new devices/equipment and operational guidelines.

Only in this way will we be able to reduce the number of deaths, life-threatening injuries and permanent disabilities caused by tractor overturns [1,42–47].

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