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*INJURY BIOMECHANICS RESEARCH*
*Proceedings of the Thirty-Fourth International Workshop*

# Proposal for a Biomechanical Autopsy

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## ABSTRACT

*In some way, the autopsy concludes the experimental phase, and, thus, results in the injury assessment. The specific needs of biomechanical research on cadavers led to the development of specific autopsy techniques in order to provide a more pertinent injury assessment.*
*According to our experience, the main elements that must be taken into account consist of:*

- *-Cause of the death.*
- *-Initial X-ray checking.*
- *-Post-mortem pleural effusion, checking and evacuation.*
- *-Post-mortem peritoneal effusion, checking and evacuation.*
- *-Injuries induced by the instrumentation.*
- *-Video and curves.*
- *-Anatomical parts tested.*
- *-Complementary tests on bones or organs.*

*All these elements contribute to the description of an autopsic approach adapted to the aim of the study.*
*The example that has been chosen concerns the thorax. On the one hand it shows how exhaustive the autopsy can be. On the other hand this exhaustiveness makes the autopsy injury assessment difficult to link to the clinical injury assessment. Facing this problem, the proposal consists of the production of two types of injury assessment by the autopsy: the regular exhaustive injury assessment and an estimated clinical injury assessment.*

## INTRODUCTION

The autopsy is the last phase of the biomechanical experimentation resulting in the injury assessment. However, the experience showed that, in field biomechanics, the autopsy has specific needs in order to obtain a more pertinent injury assessment. Consequently, before the beginning of the autopsy, an approach must be defined in order to suit the study. This means that the needs of the engineers for the analysis and all the data gathered before the autopsy must be taken into account. Despite this, some limits are reached, particularly when the autopsic injury assessment must be compared to the clinical injury assessment used in the field of accidentology. The current difficulties that are met concern the rib fracture assessment, generally majored, and the soft tissue injury assessment, generally minored.

# METHODS

## Organization of the strategy autopsy

The first element used to determine the autopsic approach is the subject of this study. Consequently, an experiment involving the head should exclude from the field of the autopsy all the other anatomical parts. Strictly doing, it could result in a loss of autopsic data. The adopted approach consists of the determination of the main loading anatomical area plus the bordering areas. The other anatomical areas are excluded from the autopsy, allowing time to be saved. Consequently, in the case of tests on the head, the dissection of the neck seems to be pertinent. On the other hand, in the case a pedestrian test, the detailed autopsy concerns all the anatomical parts. The other elements that must be taken into account in the autopsy strategy are the state of the PMHS at arrival, the instrumentation, the data gathered during the test and the explorations carried out after the test.

### *State of the PMHS at arrival*

When possible, it is valuable to get information regarding previous diseases, previous surgeries, and the cause of death in order to select more suitable PMHSs for testing. Moreover, examining the subject can give some information on previous recent or old surgeries.

### *Post mortem phenomena*

Post mortem phenomena consist of pleural effusions, a peritoneal effusion, and detachments of the superficial layer of the skin. The pleural effusion can reach a very large volume inducing important changes in the position of the organs such as the lungs, the liver and the spleen. Consequently, it seems important to correct this situation in order to obtain a position of the inner organs as realistic as possible as compared to a live subject. Draining allows this to be done, preserving the visceral pleura when incising the parietal pleura and taking care of the bladder when incising the abdomen wall above the left or right inguinal ligament. Contrary to the two first phenomena, the detachment of the skin seems to be related to the freezing. The consequences are limited to an uncomfortable manipulation of the subject, except when gluing on the skin is required.

### *Instrumentation*

Sometimes, dissection is necessary to allow for the instrumentation. This includes using strain gages on the ribs, pressure capsules inside the pleura and inside the stomach, an aortic pressure sensor, a pressure probe inside the trachea, and instrumentation of the pubic symphys with a load cell. Angular measurement of the Nyquist plane also requires dissection, as well as catheterization of the portal vein and the inferior vena cava (in order to revascularize the porto-cave system when the liver is involved during the test) and catheterization of arteries or/and veins (in order to carry out angiography).

The dissection technique must be described in order to be reproducible. The injuries induced must be minimal and discussed in order to assess the benefit in comparison to the consequences. These are of two types: changes in the behavior of the anatomical area and induction of supplementary injuries.

Sometimes, drilling and screwing is necessary to attach sensors on the bones. This technique can induce weakness and consequently result in supplementary fractures. The autopsy determines if screws are involved in fractures or not. In the first case, it can be assessed that the screwing did not induce changes in the bone solidity; in the second case, there is a doubt and it is impossible to conclude.

### *Data gathered during the test*

Analysis of the video: an unexpected motion of the whole subject or of an anatomical segment can focus the detailed autopsy on a supplementary area.

Analysis of the curves of measurement: load cells allow the loading to be assessed, especially if previous identical tests have been carried out. The analysis of the rib gage curves can provide information on the number and the sequence of the rib fractures. The analysis of the aorta pressure curve allows the quality of the injection to be assessed, etc. Some abnormal aspect of curves can be related to the failure of the instrumentation. Consequently the checking of the instrumentation shall be the first step of the autopsy: plates unscrewed, screws broken, fracture crossing the screw attachment sites, wires disconnected, gages unglued, etc.

### *Exploration carried out after the test*

X-rays: basic skeletal injuries detection.

Angiography: this is an exploratory technique for this study. The aim consists of the detection of small soft tissue injuries using vascular injection of barium sulphate. In case of small soft tissue injuries small vessels can be involved resulting in the infiltration of peripheral tissues with the intravascular liquid (barium sulphate). Despite the injection of Indian ink, some injuries are difficult to detect because of their location needing a long dissection. The hope is that the use of X-rays combined with the angiography can help to focus very detailed dissections on specific anatomical areas such as the vertebral joints.

In Figure 1, selective angiography of vertebral arteries can be seen. The subclavian arteries are dissected, catheterized, and ligatured behind the vertebral artery junctions. The superficial cervical arteries, the inferior thyroid arteries, the suprascapular arteries, and the internal thoracic arteries are ligatured. Twenty cc of Barium sulphate is injected in each vertebral artery. Doing this, the arteries of the posterior neck are visible, allowing injuries to be shown. In addition, it is possible to inject the internal vertebral venous plexus using the vertebral vein resulting in the X-ray in the Figure 2.

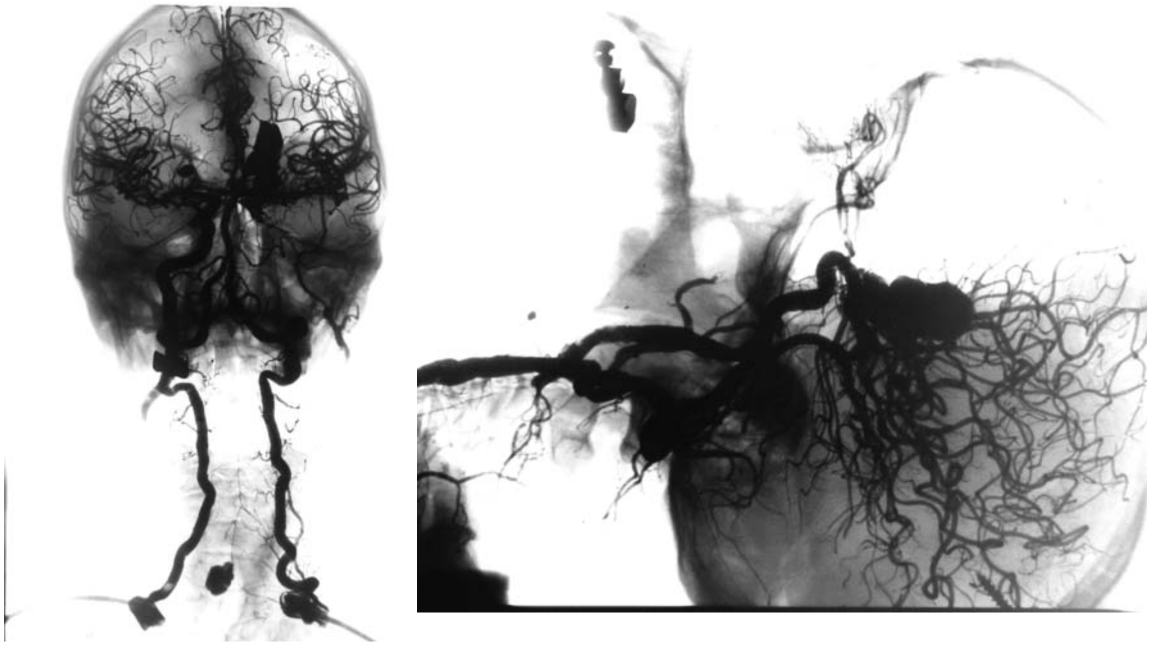

Figure 1: Selective angiography of vertebral arteries.

Figure 2: Internal vertebral venous plexus.

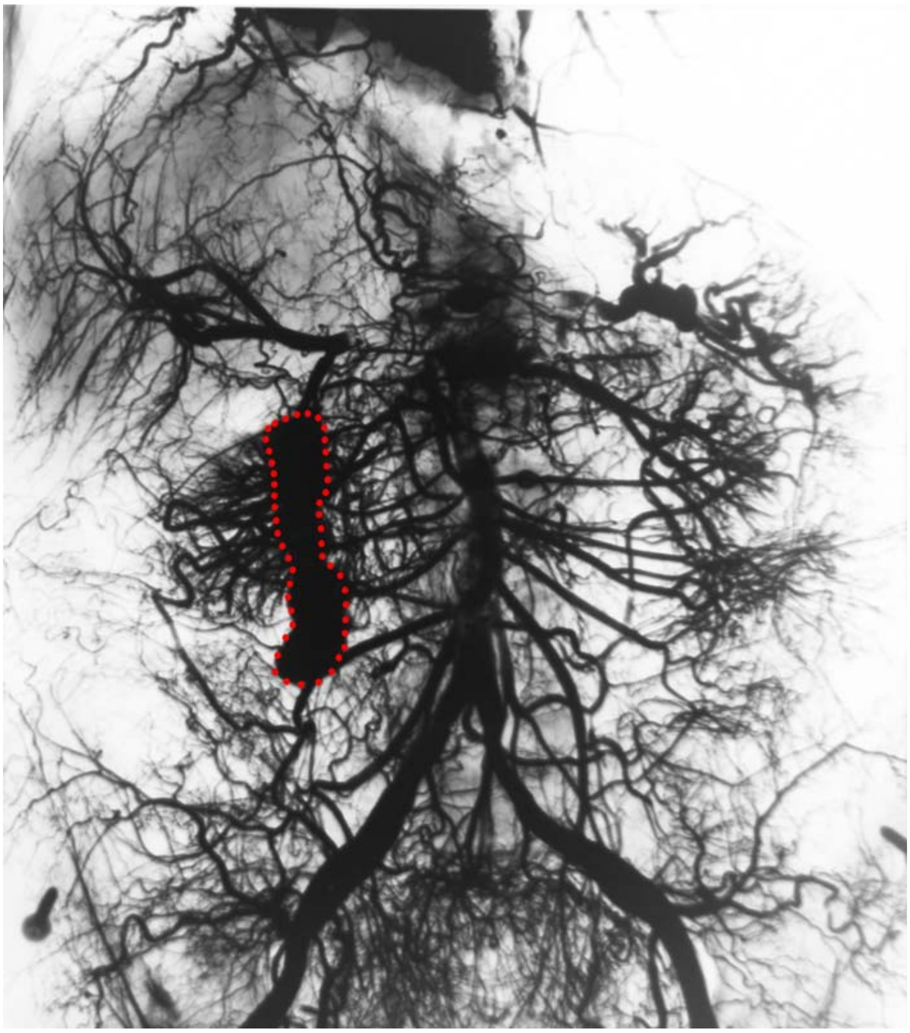

Figure 3: Arteriography of the aorta.

An arteriography of the aorta is illustrated in Figure 3. The red dotted line seen there shows the contour of a retroperitoneal hematoma after injection with barium sulphate following a loading of the abdomen. The autopsy will show a right renal artery injury. On the left, a hemorrhage of the vascular pedicle of the spleen is visible.

### *Example of an autopsy focused on the thorax*

In a test focused on the thorax, the head, the neck, the upper limb, the lower limb and the abdomen are theoretically not involved. However, in this example, the detailed autopsy must take into account the bordering area consisting of the lower part of the neck, the shoulders and the supramésocolic level of the abdomen. The other anatomical areas are excluded from the autopsy allowing time to be saved. Consequently, the detailed autopsy concerns and especially notes the following bones, organs, and associated injuries: the ribs, the sternum, the clavicle, and the potential injuries as aorta injury, supra-aortic trunks injury in case of the first and second rib fractures, myocardial contusion in case of a sternum fracture, supra-mesocolic organ injuries in case of lower rib fractures; the pleura and injuries such as pneumothorax and/or hemothorax; the diaphragm, particularly on the left, sometimes associated with intra-thoracic hernia; the lung, contusion inducing hematoma, and alveolar ruptures; the aortic isthmus showing a rupture, generally complete, sometimes partial (aneurism); tracheobronchial rupture; the liver, the spleen, and their associated injuries; and the lower cervical and thoracic vertebrae.

The sequence of the autopsy is illustrated and described in Figures 4 through 15 as follows:

Figure 4: The lower and upper limbs are amputated. The head and the upper cervical vertebrae are removed. The skin is removed. The abdominal muscles and the thoracic muscles are drawn in pink.

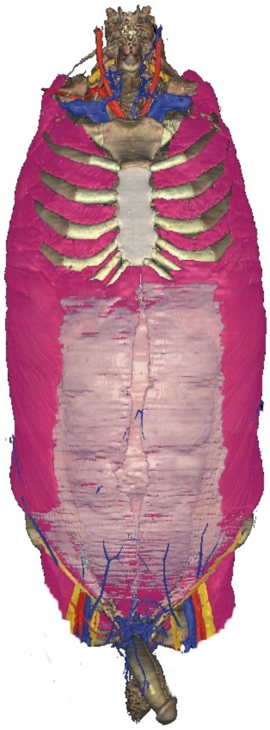

Figure 5: The scapula and the clavicle are removed including the pectoralis muscle, the deltoid muscle, the subscapularis muscle, etc.

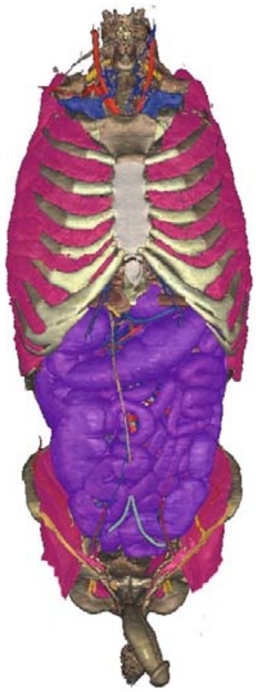

Figure 6: The abdominal cavity is opened. The colon and the small intestine are drawn in purple. The thoracic muscles, the iliopsoas muscle, the obturator internus muscles, and the cremaster muscles are drawn in pink. The pelvis and the ribs are drawn in brown.

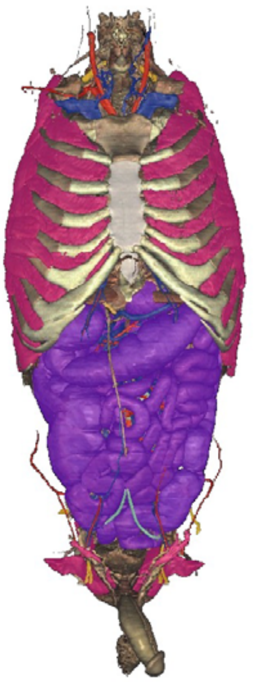

Figure 7: All the pelvic muscle insertions are severed. The perineum, the sexual organs, the sigmoid colon, and the anus are isolated from the pelvis. The intervertebral disc L5/S1 is severed. The posterior joints are dislocated. The pelvis is lowered, with the perineum making its way through the inferior and superior apertures.

Figure 8: The remaining parts after the infra-mesocolic organs, the small intestine, the ascending colon, the tranverse colon, the descending colon, the sigmoïd colon, etc. have been dissected and removed.

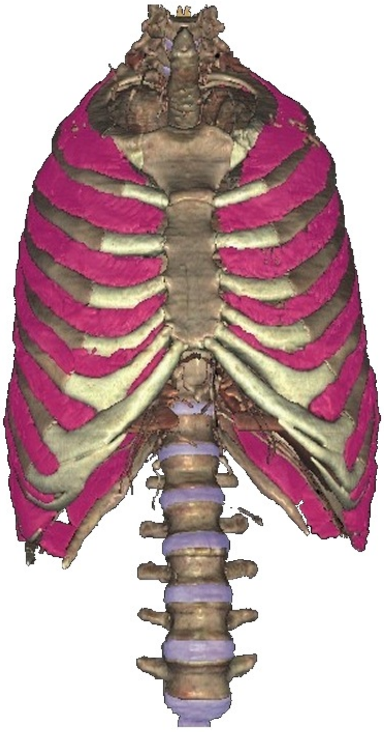

Figure 9: The remaining parts after the supramesocolic organs (liver, stomach, and spleen), retro-peritoneal organs (kidney), and diaphragm have been dissected and removed. The intercostal muscles are drawn in pink.

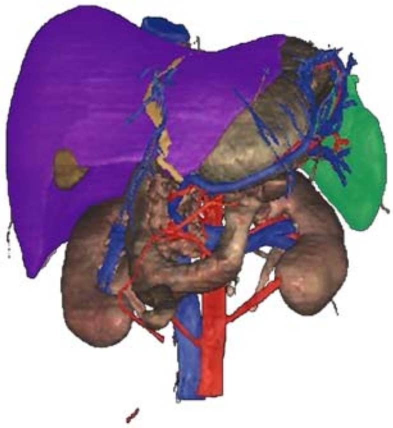

Figure 10: This drawing shows the organs removed during the previous step (liver, stomach, duodenum, spleen, kidneys). The detailed autopsy includes these organs. The liver is drawn in pink, the spleen in green, the stomach, the kidneys and the duodenum in brown. After removing these organs, the possible injuries of the diaphragm are visible.

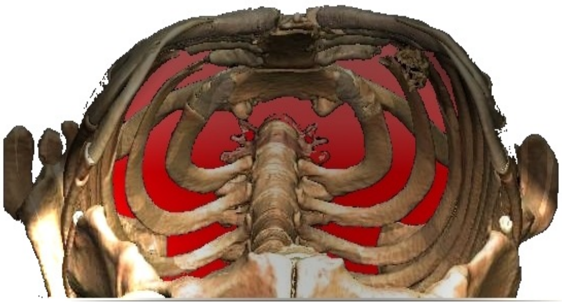

Figure 11: The inner organs of the thorax are removed. This inferior inside view of the pleural cavity allows injuries of the parietal pleura to be identified. A black hematoma (because of the Indian ink revascularization) facing a rib fracture means that soft tissues have been injured because of a relative displacement of the fracture edges during the test. Consequently, the rib fracture can be classified as separated fracture. This type of injury can be associated with a tear of the pleura, a hemothorax, and, in case of an external solution of continuity, a pneumothorax.

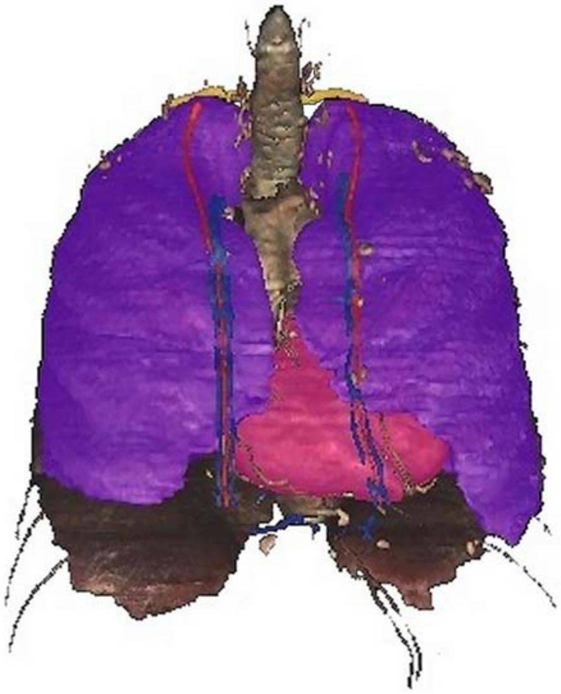

Figure 12: A detailed examination of the inner organs is carried out. The superior lobe of the right lung and the superior lobe of the left lung are drawn in purple. The inferior lobe of the right lung and the inferior lobe of the left lung are drawn in brown. The pericardium is drawn in pink. The visceral pleura is examined in order to identify tears, particularly if injuries of the parietal pleura have been previously detected. In the absence of obvious injuries, the best way to check the lungs is by inflation. In case of air leakage, the diagnostic is "pneumothorax +/- hemothorax" depending on the size of the injury. The pericardium is incised. In case of Indian ink inside the pericardium cavity, the myocardium is examined in order to detect the cause of the injury of the "hemopericardium". The heart is dissected. The heart valves are checked, particularly the sigmoid valves. The aorta is dissected and incised on its length. The tracheobronchic junctions are dissected and examined. Finally, the lungs are cut in order to detect hematoma and to check the homogeneity of the parenchyma.

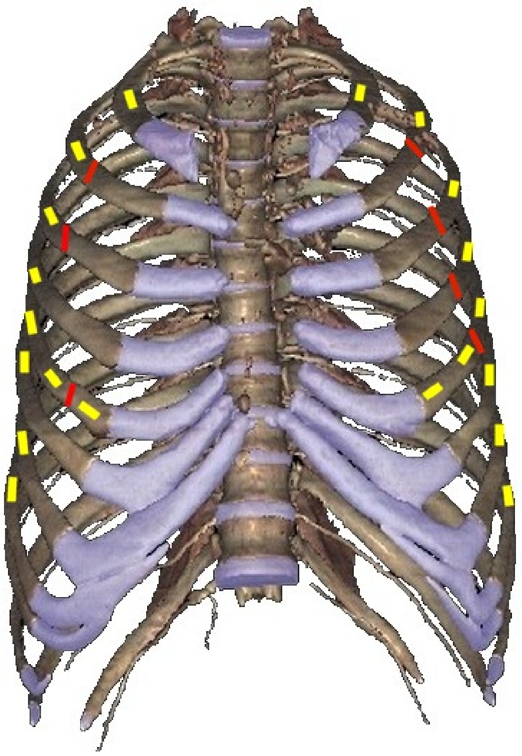

Figure 13: The last remaining part to check consists of the skeletal thorax. The sternum is removed; the intercostal muscles are cut in order to isolate each rib from the others. The majority of the muscles are quickly removed. Each rib is hand bent in order to locate the rib fractures. In case of an abnormal motion, the bone is scraped in order to identify the type of fracture (monocortical, bicortical, or separated). Several distances are measured:

-distances between the costo-transverse joints and each strain gages (rib 5 equipped with 10 strain gages). The gages are drawn in yellow. The fractures are drawn in red.

-distances between the costo-transverse joints and each rib fracture.

-the diameter of the rib cage along the various ribs.

The mobility of the costo-vertebral joints is checked.

The ribs are disarticulated and kept for future mineralization tests (3 point bending and calcinations).

Note: tests have been done with gages glued on the costal cartilage. The gages were still glued after the test and data measurement obtained. The analysis is in progress.

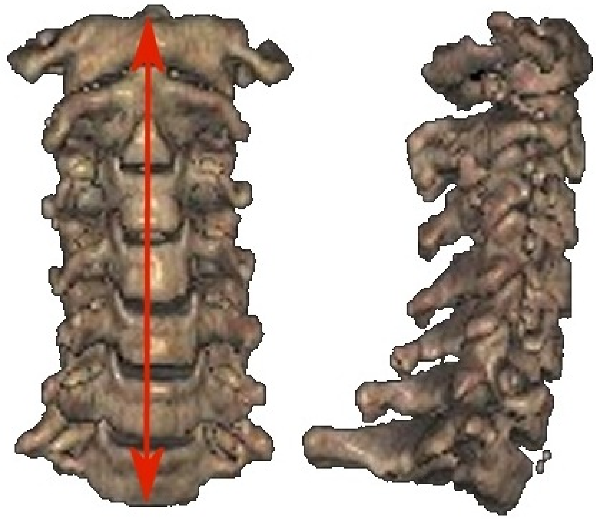

Figure 14: The cervical column is removed. A fist examination is carried out in order to detect severe injuries such as fracture (odontoïd process, vertebral body). Then, the cervical column is frozen and cut with respect to the midsagittal plane (red arrow on the drawing). The inner area, is examined, particularly the joints and cervical nerves. Finally, the cervical column is boiled during a few hours allowing small fractures to be identified.

Figure 15: Second cervical vertebra boiled and cleaned using chlorine showing a fracture of the odontoid process on the left of the picture. This way, small fractures can be detected and then perfectly described.

## RESULTS

First of all, despite all the means that can be used, the autopsy cannot be absolutely exhaustive.

*The skeleton*

On the whole, the detection of fractures is easier than the detection of the soft tissue injuries. Nevertheless, the detection of rib fractures needs an individual and meticulous examination of the ribs. In the same way, the detection of the vertebrae fractures needs a detailed dissection and/or the use of the boiling technique.

Thoracic autopsy: in case of the examination of the rib cage, the autopsy is very exhaustive and results in the classification of the rib fractures as following: bicortical separated, bicortical joined, and monocortical. Moreover, it is an accepted fact that the thoracic *clinical injury assessments* are not exhaustive particularly for the rib fractures. Consequently, the comparison of the *autopsic injury assessment* using the *autopsic AIS* to the *clinical injury assessment* using the *clinical AIS* is not reliable. This situation leads to a proposal consisting of the clinical AIS evaluation from the autopsic assessment.

Illustrated in Figure 16 is the principle of the clinical AIS evaluation from the autopsic injury assessment in order to create a link between biomechanics and accidentology. Here, the rib fractures are classified. It is considered that only separated rib fractures are detectable using standard X-rays. Taking into account all the rib fractures, the autopsic AIS is calculated. Taking into account the separated rib fractures only, the estimated clinical AIS is calculated.

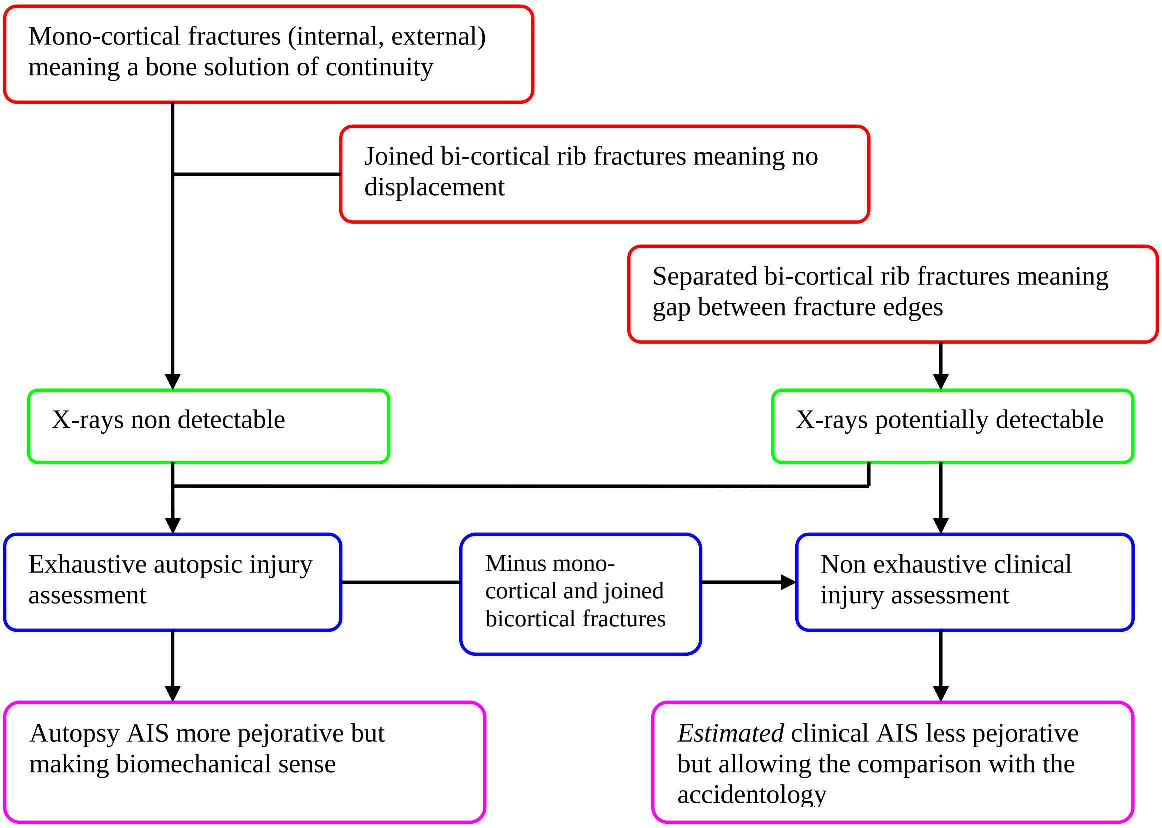


Figure 16: Principle of the clinical AIS evaluation from the autopsic injury assessment.

*The soft tissues*

The Indian ink injection is a good technique allowing small hemorrhage, small hematoma, and organ abrasion to be detected. The alcohol associated with the Indian ink allows the tissues to be fixed, and consequently, the state of the injuries kept intact until the time of the autopsy. It means that what is observed during the autopsy corresponds to a picture of the traumatic organs after an injection (arterial pressure) one minute and thirty seconds long. Among injured people, the arterial pressure is permanent, and consequently, the injuries are changing (hemorrhage, hematoma). What is the state of the injuries at the time of the examination one hour or more after the crash? The autopsy is not capable to give an answer. For example, facing liver injuries, if the hemodynamic situation of the injured person is stable, it can be decided to wait. It depends on the severity of the liver injuries. Sometime immediate surgery is necessary (pedicle injury). The autopsy can describe the type and location of injuries and can be used to assess a prognostic of evolution, but it is not really capable of providing knowledge for what would be the volume of the hemorrhage, for the hemostatic capacity of the subject, nor for what therapeutic action to take. The same problem is met with hematoma, abrasion, etc. This is why, strictly describing these injuries at the time of the autopsy can reduce the autopsic AIS in comparison to a real clinical injury assessment.

## CONCLUSION

The description of a specific technique of autopsy adapted to the biomechanical experimentation results in a specific practice that can be named “biomechanical autopsy”. The technique needs a constant improvement and adaptation until all situations are met. At this time, the technique will be coherent and optimized associating time saving and exhaustiveness with the aim of the project.

Special attention must be paid to the skeleton injury assessment that can be very exhaustive in comparison to the clinical injury assessment. This leads to the autopsic AIS (biomechanics) more pejorative than the clinical AIS (accidentology). The proposal described above could be a solution to link biomechanics and accidentology after validation of the methodology.

As to the minimized soft tissues injury assessment, the link with surgery seems to be necessary to better understand the evolution of the initial injuries and to adapt the autopsic AIS to the clinical AIS. The methodology has to be described.

## ACKNOWLEDGEMENTS

The authors wish to thank Xavier Trosseille from L.A.B. Renault-PSA, Peugeot-Citroën.

# DISCUSSION

PAPER: **Proposal for Biomechanical Autopsy**

PRESENTER: ***Pascale Potier, Experimental Pathology Laboratory and Biomechanical Experimentation Department - CEESAR***

**Q**UESTION: *Frank Pintar, Medical College of Wisconsin*
It's very interesting. We do it a little different in the sense that we do not eviscerate the organs before we examine them for injury because we've noticed that pathologists will often injure the organs while they're eviscerating. Have you a comment on that?

**A**NSWER: I don't understand all of the question.

**Q:** Evisceration of the organs.

**A:** Yeah?

**Q:** We don't do that at the Medical College of Wisconsin.

**A:** Yeah.

**Q:** When we are examining for soft tissue.

**A:** Yeah. The goal of the evisceration is to have a good view of the whole pleura and it's possible to dissect after all the inner organs have been eviscerated. They are dissected after, but this is used to have a view of the whole pleura and to detect hematoma and injuries because it makes sense. For example, a hematoma facing a rib fracture can help to identify the type of rib fracture because it means that there was soft tissue injury close to the rib fracture, and that generally is disjointed rib fracture. Using this, I think it was easier.

**Q:** Yeah. I understand it is easier to look at the whole organ when it's out of the body--

**A:** Yeah.

**Q:** But we find that inside, too, looking at the organs gives you a better idea of what was really truly injured post-mortem. Thank you.

**A:** Thank you.

**Q:** *Guy Nusholtz, Daimler Chrysler*
Just a quick question: Are you pulling the organs out, in the thorax, from underneath? They're coming down through the diaphragm? Is that it?

**A:** Yeah.

**Q:** Is that correct? So, you're not opening them up—

**A:** No.

**Q:** Through the ribcage so you don't—

**A:** No.

**Q:** Expect for fractures.

**A:** In this way to dissect the front of the spine so it—This is done without any view, you see. It's a blind dissection technique. Do you understand? Because of the size of the thorax, we do the dissection without view of what we are doing.

**Q:** So then, you're not cutting here.

**A:** No. In another time this is done. The sternum is removed, but when we have checked the cartilage and all the ribs and the intercostal muscles are removed to check each rib, and they are strapped to classify the rib fracture and to know if there is some monocortical, bicortical--

**Q:** How do you co-locate an injury in space, then?

**A:** How--?

**Q:** In other words, if I have an injury, say, in the rib and then directly under it I have an injury in the lung, how do I know which rib caused that if you remove the organs?

**A:** You see, if there is an injury of the lung, it identifies the rib. It depends on if there is only one rib or if there are many ribs, you see. And, I don't have the experience of testing with this kind of problem so I can't answer your question.

**Q:** Okay. Thank you.