Chapter 28
Physical and Biomechanical Methods of Ascertainment

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Abstract After a brief introduction on the contributions that basic sciences, such as mathematics, physics and engineering, can furnish to personal injury and damage assessment, this chapter illustrates the methods of ascertainment to be used for the biomechanical reconstruction of any traumatic collisional event. It explores, in particular, the use of special measurement tools (i.e. anthropomorphic and anthropometrical testing devices) in combination with mathematical techniques, such as the finite element modelling (FEM), for reconstructing the acceleration, velocity, trajectory and energy of the collision. These data, interpreted in combination by the biomechanical and biomedical experts, are extremely useful for reconstructing the causal link between the traumatic event and the injuries/damages suffered by the claimant.

28.1 Physical and Biomechanical Aspects

The scope of this part of the work is intended to improve the research with a supplementary contribution to medicine from biomechanics, physics and other sciences.

Any event is ruled by the physical laws. In particular, if the event is characterised by an impact that involves persons and objects, it is necessary to evaluate, from the physical point of view, the history in time of the single phases of what happened and the consequent interaction with the environment.

Synergy with physics and mathematics may be an additional tool in the strategy of the reconstruction of any event, provided that a suitable quantity of information is available.

The aspects of this methodology require, first of all, the data regarding the scenario where the event happened. It is necessary to know the scenario condition

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before and after the event, too. At a later stage a physical and mathematical model of the whole real scenario will be built using all pertinent data, available and verified.

The theoretical model thus constructed (e.g. FEM) will be processed by the mathematical calculator of a powerful computer, taking into account the aspects of specific interest (acceleration, velocity, trajectory, energy, deformation and so on). This process, composed of a variable number of computational mechanics, as compatible as possible with the precision necessary in the specific case, represents the calibration process of the whole numerical model. It is similar to the tuning of a violin string in order that the desired key be reproduced exactly.

At any tour of the calibration process, an expert analyst examines the copious amount of results and evaluates if they are in agreement with the established precision degree regarding the specific event. If necessary, he applies a corrective factor.

The model is considered suitable to properly describe the event when the results are in conformity with the established degree of precision and the error made is smaller than an established factor of control.

At this stage the model is correct and adequate to describe accurately the specific case reproducing, theoretically, the real or experimental event at any time.

As a consequence of that, the most interesting aspect regards the fact that, modifying lightly a given input parameter, it is possible to use a coherently modified model to predict a similar result or to rebuild, in a different initial hypothesis, a similar well-documented incident. Therefore, the methodology allows the expert to find the correct engineering reconstruction within a group of different solutions.

The medical expert may compare his own evaluation with the additional evaluation of the analyst engineer: if the conclusions are coincident, a new tool may be gainfully added in the ascertainment methodology of events in which a collision involves one or more persons and any kind of object.

The method is suitable to be used in many other cases.

28.2 The Injury Caused by the Collision

The cause which provokes injuries or damage to a person is generally a collision against an object, the object and the person being in relative movement.

The collision of two or more objects distributes in a different way the initial kinetic energy of the system under consideration. The masses and the velocities of the objects have a decisive role in the evolution of the event: the velocity, in particular way, has a substantial influence on the new distribution of the stress and the strain of the colliding parts.

In addition to that, the materials react differently to the impact according to its mechanical properties, and each material has different behaviours depending on its velocity of deformation. Many materials and organic tissues have different behaviours depending on the load direction, too.

It is impossible to leave out this essential aspect regarding a collision: it is often a complex event where many forces interact, in different instants and along various directions, within a specific time interval.

In this context a greater force acting later may have a lower influence if compared with a weaker force acting earlier.

28.3 Accidental Events

The aim of this chapter is to provide support, as efficient and as practical as possible, using mathematical, physical and engineering tools, to medicine in the field of medicolegal ascertainment.

In this chapter the biomechanical, physical and mathematical aspects will be discussed, with reference to traffic injury, in particular, and to all kinds of collision causing personal damages in general. To do that, it is improper to carry out calculations manually due to the large number of variables characterising the problem, but it is essential to use computational mechanics and biomechanics.

Special measurement tools, anthropomorphic and anthropometrical testing devices, ATD, react, during a collision, to the stress and deformation and other loads, transforming the mechanical impact in readable machine data (Fig. 28.1).

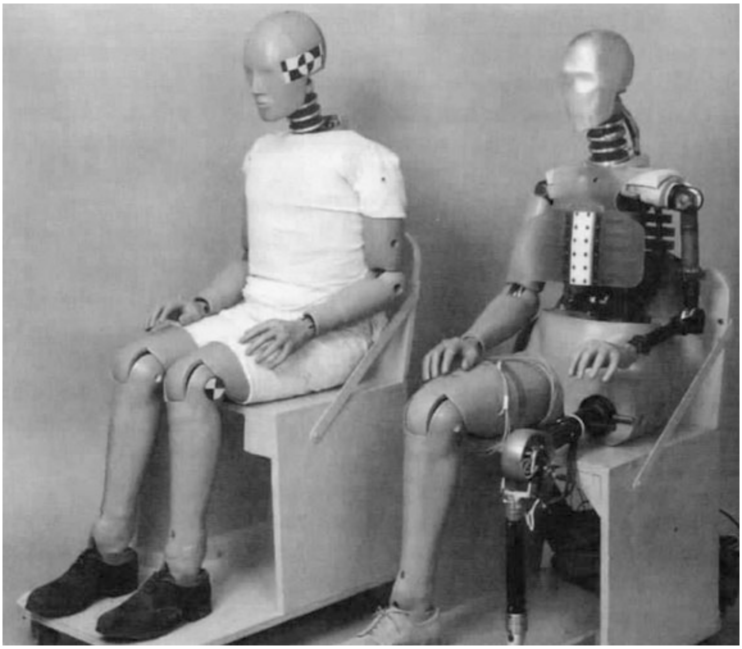


Fig. 28.1 ATD Hybrid III adult male dummy [1]

28.4 Finite Element Modelling

In mathematics, the finite element modelling, FEM, is a numerical technique for finding approximate solutions to boundary value problems for differential equations. It uses variational methods (the calculus of variations to minimise an error function and produce a stable solution), analogous to the idea that connecting many tiny straight lines can approximate a larger circle. FEM encompasses all the methods for connecting many simple element equations over many small subdomains, named finite elements, to approximate a more complex equation over a larger domain.

It foresees three fundamental phases:

1. Modelling phase: building of the physical and mathematical model equivalent to the real system, including the theoretical (FEM) anthropometrical test devices
2. Activation phase of mathematical calculation phase: data processing and output of numerical results
3. Rendering phase: summary of the numerical results by means of a specific software that uses graphic tools

The numerical results include the data relevant to the theoretical anthropometrical testing devices, ATD, readable by the biomechanical engineer and to be interpreted by the medical specialist and by the biomechanical engineer as well (Fig. 28.2).

The first phase of the FEM procedure is the material characterisation of each material present into the scenario.

Any inorganic material and any biological tissue have their own mechanical property expressed by their physical quantity, and it is necessary to utilise the correct value in the FEA code to perform a valid analysis (Figs. 28.3 and 28.4).

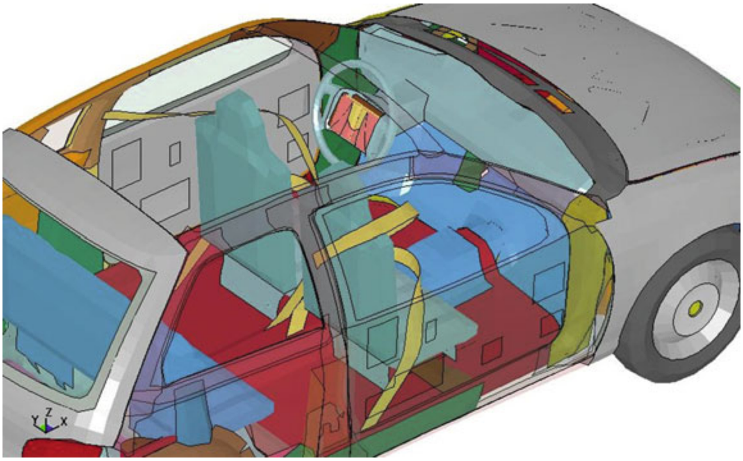


Fig. 28.2 FEM model of a small car

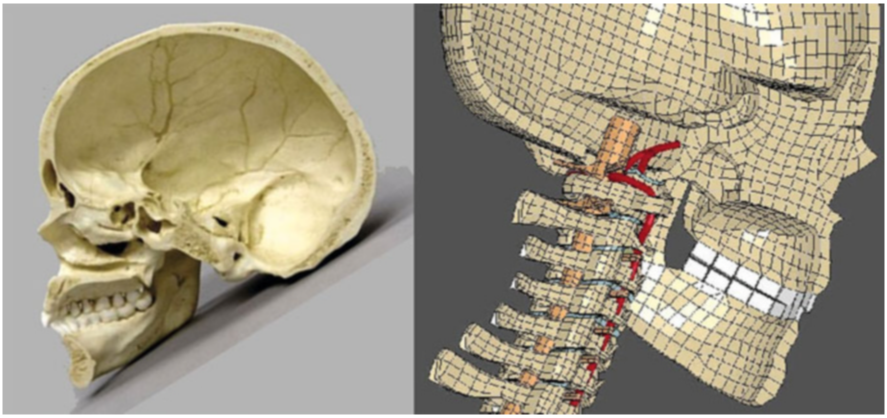
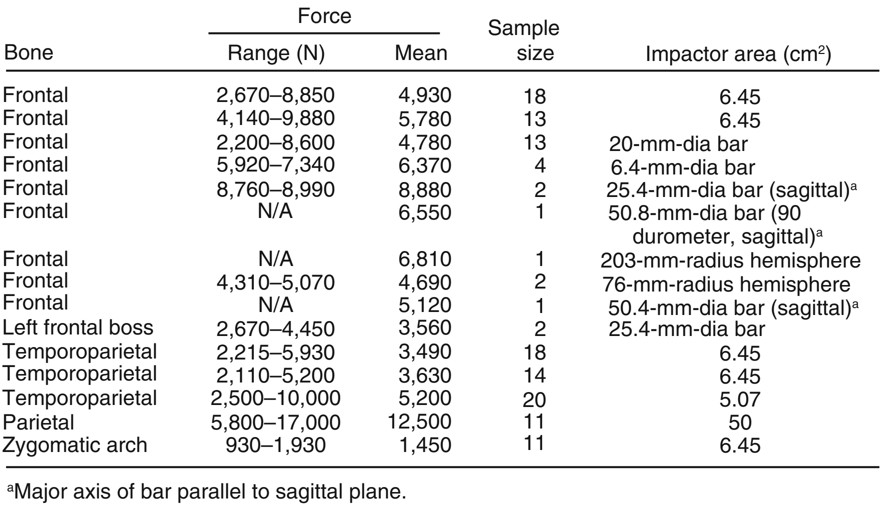


Fig. 28.3 Real skull and theoretical skull FEM model



Bone	Force		Sample size	Impactor area (cm^2)
	Range (N)	Mean		
Frontal	2,670–8,850	4,930	18	6.45
Frontal	4,140–9,880	5,780	13	6.45
Frontal	2,200–8,600	4,780	13	20-mm-dia bar
Frontal	5,920–7,340	6,370	4	6.4-mm-dia bar
Frontal	8,760–8,990	8,880	2	25.4-mm-dia bar (sagittal)[a]
Frontal	N/A	6,550	1	50.8-mm-dia bar (90 durometer, sagittal)[a]
Frontal	N/A	6,810	1	203-mm-radius hemisphere
Frontal	4,310–5,070	4,690	2	76-mm-radius hemisphere
Frontal	N/A	5,120	1	50.4-mm-dia bar (sagittal)[a]
Left frontal boss	2,670–4,450	3,560	2	25.4-mm-dia bar
Temporoparietal	2,215–5,930	3,490	18	6.45
Temporoparietal	2,110–5,200	3,630	14	6.45
Temporoparietal	2,500–10,000	5,200	20	5.07
Parietal	5,800–17,000	12,500	11	50
Zygomatic arch	930–1,930	1,450	11	6.45

[a] Major axis of bar parallel to sagittal plane.

Fig. 28.4 Skull fracture force [1]

The interaction between inorganic objects and anatomical parts and tissues is the cause of the injury or damage if its value is greater than the specific collapse threshold.

The ultimate threshold depends on the material properties, material behaviour, speed impact, load direction and other conditions. Mainly it depends on time (and, consequently, on speed impact and the sequence of events) (Fig. 28.5).

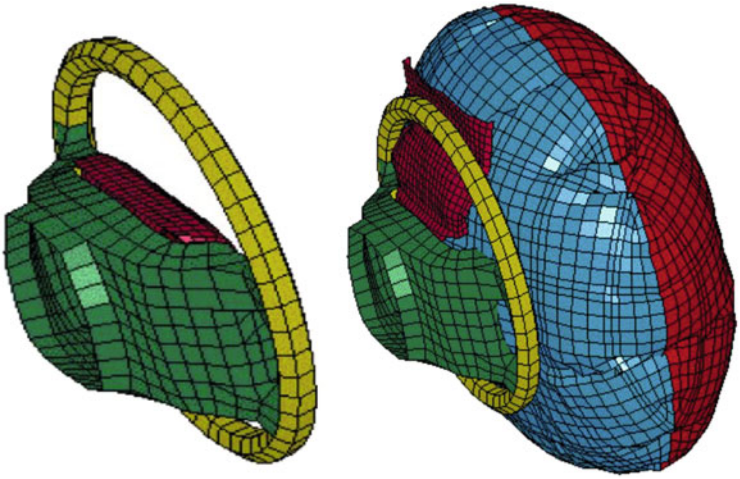


Fig. 28.5 Car steering wheel and exploded air bag

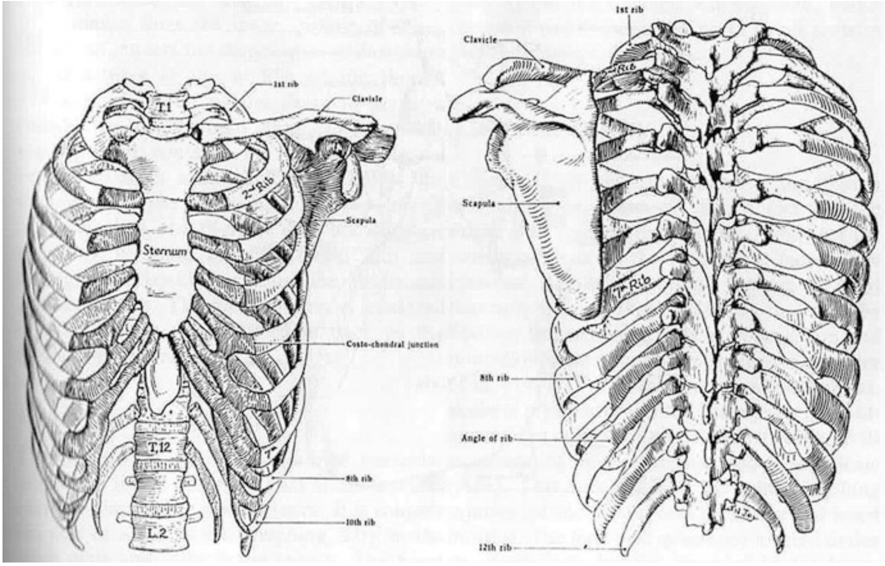


Fig. 28.6 Thorax bones mainly exposed to collisions [1]

So, the force, due to the shoulder belt and due to the air bag, acting on the thorax bones, depends on the relative impact acceleration (in this due to the velocity of the car). In the case of high value of the velocity of the collision, the thorax bones react with fragile fractures of the ribs, whereas in the case of low speed the interaction affects a larger area of the thorax and assumes the behaviour of a light diffused compression, sometimes without any fracture (Figs. 28.6 and 28.7).

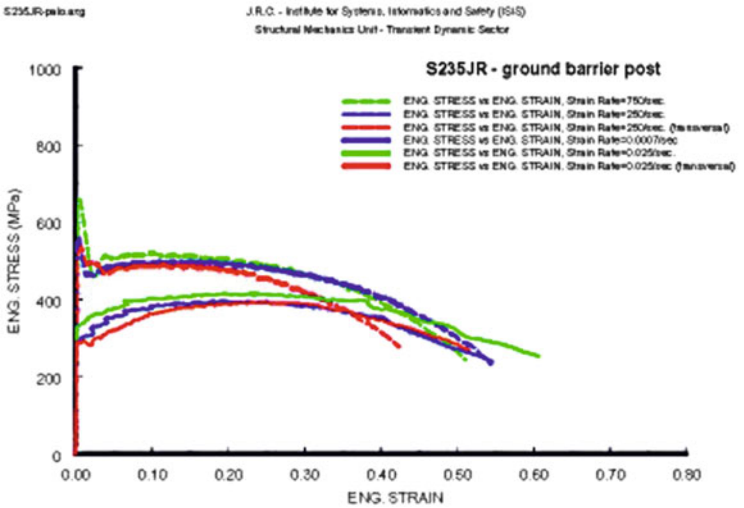


Fig. 28.7 Relationship between stress and strain in the case of different speed

28.5 Time History of Variables and Causality

To evaluate if a relationship of cause and effect exists, it is necessary to reconsider the concept according to which, within a time interval, the events that occur before the others in the domain of reference are more important in determining causality than the compatible effects that it is possible to observe.

If the compatibility with the specific injury or damage exists, in fact, the previous event is the effective cause of the visible harmful effects, since the following event occurs when the scenario has been modified completely and irreversibly.

Consequently, during the accident phases, the events that occur after the first compatible event cannot be considered the cause of the damage, even if they are compatible with the specific damage and more harmful than the preceding event (Fig. 28.8).

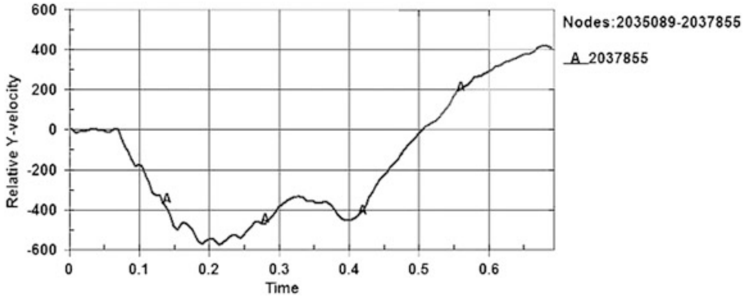


Fig. 28.8 Example of the time history of the relative y velocity

28.6 Relationship Between the Anthropometrical Device Deformation and Personal Damage

The ATD Hybrid III was designed and realised by the General Motors Company in many versions and editions with the aim of studying the safety of its cars in traffic.

Thus, the resistance of the parts of the device is compatible with the resistance of the corresponding parts of the human body.

During the phases of a major road collision, an ATD may crash time after time and receive innumerable stresses and deformations compatible with a specific damage threshold.

The events that occur after the first compatible event cannot be considered the cause of the mechanical damage, even if they are compatible with the specific threshold or more harmful than it.

It is necessary to consider the combined effect of all the crashes and—first of all—to determine which event occurred previously (Fig. 28.9).

The medical specialist in traumatology has many abilities available for evaluating the correct sequence of particular events.

In addition to that, the supplementary contributions of a FEA permit the analyst to correlate any variable pertinent value with the collision time interval, setting the time of any event and the instant value of any variable.

This brief consideration regarding the supplementary contributions to the medicolegal ascertainment methodology from other sciences, such as biomechanics, physics, mathematics and engineering, mainly pointed out the following aspects:

- It is essential to evaluate the scenario's geometry and the mechanical properties of the materials, including its own behaviour in dynamics.
- One of the most effective supplementary tools regarding the medicolegal ascertainment methodology appears to be the finite element analysis, FEA method. Its codes show the values of any variable in time and, consequently, allow one to understand, at any time since the beginning of the collision, the behaviour assumed by any object and its variables, ATD included.

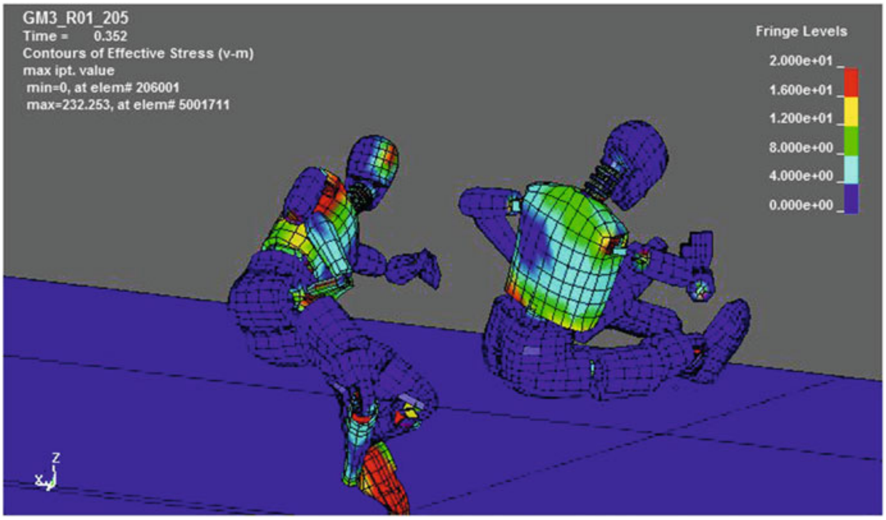


Fig. 28.9 Stress render of ATD during a collision

- The most probable cause of the damage or injury seems to be the first event compatible with the peculiar threshold of reference. In fact, during the accident phases, the events that occur after the first one compatible with a significant injury or damage cannot be considered the cause of the accident, even if they are compatible with the first damaging event and are more harmful.
- This peculiarity of the FEA method is fundamental to determine causality with the effects of the compatible harmful event that are possible to observe. That is the reason why the FEA method is one of the most useful supplementary tools in medicolegal ascertainment procedures.

Many aspects have to be further examined, and the detailed study of the impacts appears strictly necessary from several further points of view.

Reference

1. Nahum AM, Melvin JW (eds) (1993) Accidental injury biomechanics and prevention. Springer, New York, pp 292–310