New Universal Theory of Injury Prediction and Prevention

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The prediction and prevention of traumatic brain injury, spinal injury and musculo-skeletal injury is a very important aspect of preventive medical science. Recently, in a series of papers [1, 2, 3], I have proposed a new coupled loading-rate hypothesis as a unique cause of all above injuries. This new hypothesis states that the main cause of all mechanical injuries is a Euclidean Jolt, which is an impulsive loading that strikes any part of the human body (head, spine or any bone/joint) – in several coupled degrees-of-freedom simultaneously. It never goes in a single direction only. Also, it is never a static force. It is always an impulsive translational and/or rotational force coupled to some mass eccentricity. This is, in a nutshell, my universal Jolt theory of all mechanical injuries.

Figure 1: Human brain and its SE(3)-group of microscopic three-dimensional motions within the cerebrospinal fluid inside the cranial cavity.

To show this, based on the previously defined covariant force law, I have firstly formulated the fully coupled Newton–Euler dynamics of:
1. Brain’s micro-motions within the cerebrospinal fluid inside the cranial cavity;
2. Any local inter-vertebral motions along the spine; and
3. Any local joint motions in the human musculo-skeletal system.
Then, from it, I have defined the essential concept of **Euclidean Jolt**, which is the main cause of all mechanical injuries. The Euclidean Jolt has two main components:

1. Sudden motion, caused either by an accidental impact or slightly distorted human movement; and
2. Unnatural mass distribution of the human body (possibly with some added masses), which causes some mass eccentricity from the natural physiological body state.

![Diagram of human body representation in terms of SE(3)/SE(2)-groups of rigid-body motion, with the vertebral column represented as a chain of 26 flexibly-coupled SE(3)-groups.](image)

What does this all mean? I’ll try to explain it in “plain English”. As we live in a 3D space, one could think that motion of any part of the human body, either caused by an accidental impact or by voluntary human movement, “just obeys classical mechanics in 6 degrees-of-freedom: three translations and three rotations”. However, these 6 degrees-of-freedom are not independent motions as it is suggested by the standard term “degrees-of-freedom”. In reality, these six motions of any body in space are coupled. Firstly, three rotations are coupled in the so-called rotation group (or matrix, or quaternion). Secondly, three translations are coupled with the rotation group to give the full Euclidean group of rigid body motions in space. A simple way to see this is to observe someone throwing an object in the air or hitting a tennis ball: how far and where it will fly depends not only on the standard “projectile” mechanics, but also on its local “spin” around all three axes simultaneously. Every golf and tennis player knows this simple fact. Once the spin is properly defined we have a “fully coupled Newton–Euler dynamics” – to start with.

The covariant force law for any biodynamical system (which I introduced earlier in my biodynamics books and papers, see my references in the cited papers above) goes one step beyond the Newton–Euler dynamics. It states:

**Euclidean Force covector field** = **Body mass distribution** × **Euclidean Acceleration vector field**

This is a nontrivial biomechanical generalization of the fundamental Newton’s definition of the force acting on a single particle. Unlike classical engineering mechanics of multi-body systems, this fundamental law of biomechanics proposes that forces acting on a multi-body system and causing its motions are fundamentally different physical quantities from the resulting accelerations. In simple words, forces are massive quantities while accelerations are massless quantities. More precisely, the acceleration vector field includes all linear and angular
accelerations of individual body segments. When we couple them all with the total body’s mass-distribution matrix of all body segments (including all masses and inertia moments), we get the force co-vector field, comprising all the forces and torques acting on the individual body segments. In this way, we have defined the 6-dimensional Euclidean force for an arbitrary biomechanical system.

Figure 3: Schematic latero-frontal view of the left knee joint. Although designed to perform mainly flexion/extension (strictly in the sagittal plane) with some restricted medial/lateral rotation in the semi-flexed position, it is clear that the knee joint really has at least six-degrees-of-freedom, including three micro-translations. The injury actually occurs when some of these microscopic translations become macroscopic, which normally happens only after an external jolt.

Now, for prediction of injuries, we need to take the rate-of-change (or derivative, with respect to time) of the Euclidean biomechanical force defined above. In this way, we get the Euclidean Jolt, which is the sudden change (in time) of the 6-dimensional Euclidean force:

$$\text{Euclidean Jolt covector field} = \text{Body mass distribution} \times \text{Euclidean Jerk vector field}$$

And again, it consists of two components: (i) massless linear and angular jerks (of all included body segments), and (ii) their mass distribution. For the sake of simplicity, we can say that the mass distribution matrix includes all involved segmental masses and inertia moments, as well as “eccentricities” or “pathological leverages” from the normal physiological state.

Therefore, the unique cause of all brain, spine and musculo-skeletal injuries has two components:
1. Coupled linear and angular jerks; and
2. Mass distribution with “eccentricities”.

In other words, **there are no injuries in static conditions without any mass eccentricities; all injuries are caused by mutually coupled linear and angular jerks, which are also coupled with the involved human mass distribution.**
Note the difference between jerk and jolt. For example, sharp braking in a car causes jerk, while actual colliding with another object causes jolt. And it is always in several directions and rotations combined.

The Euclidean Jolt causes two forms of discontinuous brain, spine or musculo-skeletal injury:
1. Mild rotational disclinations; and
2. Severe translational dislocations (or, fractures).

In the cited papers above, I have developed the soft-body dynamics of biomechanical disclinations and dislocations, caused by the Euclidean Jolt, using the Cosserat multipolar viscoelastic continuum model.

Implications of the new universal theory are various, as follows.

A. The research in traumatic brain injury (TBI, see Figure[1]) has so far identified the rotation of the brain-stem as the main cause of the TBI due to various crashes/impacts. The contribution of my universal Jolt theory to the TBI research is the following:

1. Rigorously defined this brain rotation as a mechanical disclination of the brain-stem tissue modelled by the Cosserat multipolar soft-body model;
2. Showing that brain rotation is never uni-axial but always three-axial;
3. Showing that brain rotation is always coupled with translational dislocations. This is a straightforward consequence of my universal Jolt theory.

These apparently ‘obvious’ facts are actually radically new: we cannot separately analyze rapid brain’s rotations from translations, because they are in reality always coupled.

One practical application of the brain Jolt theory is in design of helmets. Briefly, a ‘hard’ helmet saves the skull but not the brain; alternatively, a ‘soft’ helmet protects the brain from the collision jolt but does not protect the skull. A good helmet is both ‘hard’ and ‘soft’. A proper helmet would need to have both a hard external shell (to protect the skull) and a soft internal part (that will dissipate the energy from the collision jolt by its own destruction, in the same way as a car saves its passengers from the collision jolt by its own destruction).

Similarly, in designing safer car air-bags, the two critical points will be (i) their placement within the car, and (ii) their “soft-hard characteristics”, similar to the helmet characteristics described above.

B. In case of spinal injury (see Figure[2], the contribution of my universal Jolt theory is the following:

1. The spinal injury is always localized at the certain vertebral or inter-vertebral point;
2. In case of severe translational injuries (vertebral fractures or discus herniae) they can be identified using X-ray or other medical imaging scans; in case of microscopic rotational injuries (causing the back-pain syndrome) they cannot be identified using current medical imaging scans;
3. There is no spinal injury without one of the following two causes:
   a. Impulsive rotational + translational loading caused by either fast human movements or various crashes/impacts; and/or
   b. Static eccentricity from the normal physiological spinal form, caused by external loading;
   c. Any spinal injury is caused by a combination of the two points above: impulsive rotational + translational loading and static eccentricity.
This is a straightforward consequence of my universal Jolt theory. We cannot separately analyze translational and rotational spinal injuries. Also, there are no “static injuries” without eccentricity. Indian women have for centuries carried bulky loads on their heads without any spinal injuries; they just prevented any load eccentricities and any jerks in their motion.

The currently used “Principal loading hypothesis” that describes spinal injuries in terms of spinal tension, compression, bending, and shear, covers only a small subset of all spinal injuries covered by my universal Jolt theory. To prevent spinal injuries we need to develop spinal jolt awareness: ability to control all possible impulsive spinal loadings as well as static eccentricities.

C. In case of general musculo-skeletal injury (see Figure 3 for the particular case of knee injury), the contribution of my universal Jolt theory is the following:

1. The injury is always localized at the certain joint or bone and caused by an impulsive loading, which hits this particular joint/bone in several coupled degrees-of-freedom simultaneously;
2. Injury happens when most of the body mass is hanging on that joint; for example, in case of a knee injury, when most of the body mass is on one leg with a semi-flexed knee — and then, caused by some external shock, the knee suddenly “jerks” (this can happen in running, skiing, and ball games, as well as various crashes/impacts); or, in case of shoulder injury, when most of the body mass is hanging on one arm and then it suddenly jerks.

To prevent these injuries we need to develop musculo-skeletal jolt awareness. For example, never overload a flexed knee and avoid any kind of uncontrolled motions (like slipping) or collisions with external objects.

References

[1] V.G. Ivancevic, New mechanics of traumatic brain injury, Cogn. Neurodyn. 3:281-293, (2009) http://www.springerlink.com/content/p27023577564202h/?p=4351a9d0d76a4f4d4b45d6720dad056f3&pi=8 arXiv:0805.3583

[2] V.G. Ivancevic, New mechanics of spinal injury, IJAM, 1(2): 387–401, (2009) http://www.worldscinet.com/ijam/01/0102/S1758825109000174.html arXiv:0806.3340

[3] V.G. Ivancevic, New mechanics of generic musculo-skeletal injury, BRL, 4(3):273–287, (2009) http://www.worldscinet.com/brl/04/0403/S1793048009001022.html arXiv:0807.1759