International Journal of Innovative Healthcare Research 12(4):1-7, Oct-Dec, 2024

 www.seahipublications.org **ISSN: 2354-2950**

DOI:10.5281/zenodo.13886011

Physics of Trauma Care and Management: A Review Article

Sirisena Anil U.I.[1*]& Benard John O.[2]

[1]Medical Physics Unit, Department of Radiology, Jos University Teaching Hospital, Jos, Nigeria

[2]Department of Hospital Services, Federal Ministry of Health, Abuja, Nigeria

***Corresponding Author's E-Mail: shallom2k3@yahoo.com**

ABSTRACT

The Physics of trauma plays a vital role in understanding how injuries occur and how they can be mitigated. By utilizing core principles of mechanics, energy transfer, momentum, and material science, the dynamics of injury events become clearer, providing insights into both the cause and prevention of trauma. This interdisciplinary approach enables us to assess the forces at play during accidents and design more effective protective strategies. As research continues to advance, innovations in injury prevention technologies will significantly enhance safety measures in fields such as motor vehicle safety, sports, and military operations. Furthermore, the application of Physics in trauma management extends across every phase of patient care, from the accident scene to emergency treatment and rehabilitation. Medical professionals equipped with a deeper understanding of Physics are better able to assess injuries, stabilize patients, and implement appropriate diagnostic and therapeutic interventions. As medical technology evolves, the integration of Physics into trauma care is becoming increasingly critical, improving patient outcomes and ultimately saving lives. This article highlights the evolving importance of Physics in trauma management, stressing its indispensable role in reducing injury severity and enhancing overall safety in various high-risk environments.

Keywords: Trauma Physics, Energy Transfer, Safety Technologies, Trauma Management, Injury Prevention.

INTRODUCTION

Trauma, in a broad sense, refers to the physical injuries that occur as a result of an external force or impact on the human body. These injuries can range from minor bruises to severe damage to organs, bones, and tissues, and often involve complex interactions between the body and the environment. The application of Physics to trauma helps in understanding the mechanisms of injury, predicting injury patterns, and designing preventive strategies such as protective gear and safer environments (Nahum & Melvin, 2002). By studying the Physics behind traumatic injuries, medical professionals and engineers can better assess and treat patients, while also contributing to innovations in safety systems.

This article reviews the fundamental principles of Physics that govern trauma, including concepts from mechanics, energy transfer, momentum, and material properties. We explore how these principles apply to various types of trauma, including blunt force, penetrating injuries, and trauma caused by rapid acceleration or deceleration. Additionally, we discuss modern developments in trauma biomechanics and injury prevention technologies.

Mechanics of Trauma

Trauma can be analyzed using the principles of mechanics, which is the branch of Physics that deals with the motion of objects and the forces acting upon them. In the context of trauma, the body can be viewed as a mechanical system, and injuries can be understood as the result of forces exceeding the structural limits of the body's tissues (Hall & O'Toole, 2019).

Newton's Laws of Motion

Newton's laws of motion provide a fundamental framework for understanding trauma. The first law (the law of inertia) states that an object will remain at rest or in uniform motion unless acted upon by an external force. In trauma, this concept is relevant in scenarios such as vehicular collisions, where the sudden deceleration of a car leads to forces that can cause injury to the occupants (Nahum & Melvin, 2002).

Newton's second law relates force, mass, and acceleration, as described by the equation:

$$F = ma \quad (1)$$

where F is the force applied, m is the mass, and a is the acceleration. This law is essential in trauma analysis, as it shows that the force experienced by a body is proportional to the rate of change of its velocity. For example, in a fall, the acceleration due to gravity causes a rapid increase in velocity, and the force of impact upon hitting the ground can cause fractures, concussions, or internal injuries (Cooper, 1996).

Newton's third law states that for every action, there is an equal and opposite reaction. In the context of trauma, this principle explains why, in collisions, both the object and the person experience forces. When a person hits the dashboard in a car accident, the dashboard exerts a force on the person's body equal in magnitude to the force the body exerts on the dashboard, which can result in injury depending on the impact's intensity (Hall & O'Toole, 2019).

Energy Transfer in Trauma

Trauma results from the transfer of energy to the body, with injuries occurring when tissues are unable to dissipate the energy efficiently. Kinetic energy is the most relevant form of energy in many traumatic injuries, and it is given by the equation:

$$KE = \frac{1}{2} mv^2 \quad (2)$$

where K E is the kinetic energy, m is the mass, and v is the velocity. This equation shows that the velocity of an object (or person) has a much greater influence on the energy involved in a traumatic event than the mass does. This is why high-speed collisions result in more severe injuries than low-speed ones (Yoganadan & Nahum, 2014).

Blunt Force Trauma

Blunt force trauma occurs when a non-penetrating object impacts the body, transferring energy over a relatively large surface area. The distribution of force across the body determines the extent of injury. For instance, in a car crash, the impact of the steering wheel against the chest may cause rib fractures, pulmonary contusions, or damage to internal organs (Cooper, 1996). The energy transfer in blunt trauma is often distributed over time and space, but the body's ability to absorb this energy without injury is limited.

The severity of blunt force trauma can be predicted by the force applied and the area over which the force is distributed. The relationship between force, pressure, and area is given by:

$$P = F/A \quad (3)$$

where P is the pressure, F is the force, and A is the area. If the area over which the force is applied decreases (e.g., being hit with a sharp edge), the pressure increases, resulting in more severe injury (Hall & O'Toole, 2019).

Penetrating Trauma

Penetrating trauma involves the transfer of energy to the body through a concentrated point of entry, such as a bullet or a knife. The kinetic energy of the penetrating object is transferred to the tissues it passes through, causing localized damage. In ballistic injuries, the severity of the injury depends on the speed and mass of the projectile, as well as the path it takes through the body (Gennarelli & Thibault, 1982).

The extent of the tissue damage in penetrating trauma can also be influenced by cavitation effects, where a high-velocity object (such as a bullet) creates a temporary cavity that damages tissues beyond the direct path of the object. This phenomenon is primarily due to the transfer of kinetic energy to the surrounding tissue (Lee & Laksari, 2019).

Momentum and Trauma

Momentum, defined as the product of mass and velocity, is another key concept in the Physics of trauma. The principle of conservation of momentum states that in a closed system, the total momentum before an impact is equal to the total momentum after the impact. In the context of trauma, momentum exchange between two bodies can result in injury (Stapp, 1963).

For example, consider a pedestrian struck by a car. The pedestrian initially has a low momentum, while the car has a high momentum due to its mass and velocity. During the collision, momentum is transferred from the car to the pedestrian, causing rapid acceleration of the pedestrian's body. This sudden change in momentum, often referred to as "impulse," is the cause of the injury (Hall & O'Toole, 2019). The impulse experienced by the pedestrian is given by the equation:

$$J = \Delta p = F \cdot \Delta t \qquad (4)$$

where J is the impulse, Δp is the change in momentum, F is the force, and Δt is the duration of the impact. Longer impact times (i.e., when the force is applied over a longer duration) can reduce the severity of the injury. This is why airbag deployment in vehicles can mitigate injuries by increasing the time over which the force is applied, thereby reducing the force experienced by the occupants (Crandall et al., 2013).

Biomechanics of Trauma

The study of biomechanics in trauma focuses on understanding how the body responds to forces and how injuries occur at a physiological level. This involves not only the Physics of forces but also the material properties of human tissues. Different tissues in the body have varying thresholds for injury, depending on factors such as elasticity, tensile strength, and compressive strength (Rudd & Chawla, 2010).

Stress and Strain in Biological Tissues

In Physics, stress is defined as the force per unit area applied to an object, while strain is the deformation or displacement of the object in response to stress. In the context of trauma, stress is applied to tissues (e.g., bone, muscle, or skin), and strain is the resulting deformation that can lead to injury (Yoganadan & Nahum, 2014). The relationship between stress (σ) and strain (ϵ) is characterized by the material's elastic modulus (E):

$$\sigma = E \cdot \epsilon \qquad (5)$$

Different tissues have different elastic moduli, meaning they respond differently to stress. Bone, for instance, is much stiffer and less elastic than soft tissues like skin or muscles. When the stress on a tissue exceeds its strength (its ultimate tensile strength or compressive strength), it can result in fractures, tears, or ruptures (Cooper, 1996). The advancements, such as finite element analysis (FEA), help to simulate human tissue responses to trauma, leading to better injury prediction and personalized protective gear. The equation (4) can be used to model how different materials in the body respond to impact force (Imam et al., 2023; Bruna-Rosso & Beauséjour, 2024). Using such advanced simulations, trauma engineers can predict injury patterns more accurately and develop personalized protective solutions.

Fractures and Bone Biomechanics

Bone fractures are a common result of traumatic forces that exceed the bone's strength. The force required to cause a fracture depends on the bone's geometry, the direction of the force, and the rate at which the force is applied (Seeman, 2008). Bones are strongest in compression and weaker in tension and shear. This explains why certain types of impacts, such as falls where the body absorbs compressive forces, result in fewer fractures compared to lateral impacts, which place bones under tensile or shear stress [9].

The mechanics of fractures can be described using the stress equation:

$$\sigma = F/A \tag{6}$$

where σ is the stress, F is the force, and A is the cross-sectional area of the bone. When the applied force exceeds the bone's ability to withstand stress, a fracture occurs. The fracture patterns depend on the direction and magnitude of the force, as well as the speed of application (Pankaj, 2013).

Patient-Specific Factors

Trauma outcomes are also influenced in particular by age and pre-existing conditions. For instance, decreasing bone density causes fractures in elderly people with osteoporosis with lesser forces (El-Qawaqzeh et al., 2024). The equation (6) shows how reduced bone cross-sectional area makes them more prone to injury (Pankaj, 2013; Clark, Ness & Tobias, 2008; Riggs et al., 2004). In patients with weaker bones (e.g., due to age or osteoporosis), the cross-sectional area and bone density decrease, making them more susceptible to fractures under lower forces. Tailored medical interventions can be developed by understanding these variations (Esenyel et al., 2011).

Trauma in High-Speed Collisions

High-speed collisions, such as those that occur in vehicular accidents or falls from great heights, introduce unique challenges in trauma analysis. The human body is designed to withstand certain forces, but when these forces exceed the limits of tissues, severe injuries occur (McElhaney et al., 1976).

In these scenarios, rapid deceleration causes massive energy transfer to the body. The amount of force experienced during deceleration can be calculated using the equation:

$$F = m \cdot (\Delta v/\Delta t) \tag{7}$$

where Δv is the change in velocity and Δt is the time over which the deceleration occurs. In crashes where Δt is small, the forces on the body can be extremely high, leading to severe injuries such as traumatic brain injury, internal bleeding, and broken bones (Crandall et al., 2013).

Injury Prevention and Safety Systems

Understanding the physics of trauma has led to the development of safety systems designed to mitigate injuries. These include airbags, seat belts, helmets, and body armor, all of which function by extending the time over which forces are applied, thereby reducing the peak forces experienced by the body (Lissner et al., 1960).

Airbags and Impact Mitigation

Airbags deploy in milliseconds during a crash, cushioning the occupant and reducing the forces acting on the body. By increasing the time of impact, airbags lower the forces applied to the head, neck, and chest, minimizing the risk of severe injury (Hall & O'Toole, 2019). Using the equation (4), the role of airbags in lowering peak forces on the body during collisions becomes clear, in real-world cases, increasing Δt (time of impact) via airbags reduces F (force), minimizing injury severity (Brosing & Griffith, 2021).

Helmets and Shock Absorption

Helmets are designed to absorb and dissipate energy, reducing the forces transmitted to the skull and brain during impacts. The effectiveness of a helmet can be analyzed using principles of energy conservation, where the kinetic energy of the impact is absorbed by the helmet material rather than being transferred to the head (King et al., 1979).

Application of Physics in Trauma Management

(i) Hospital Care: Diagnostic Imaging and Surgical Intervention

Upon arrival at the hospital, the role of physics in trauma management becomes even more pronounced. Diagnostic imaging technologies such as X-rays, CT scans, and MRIs are essential tools that rely heavily on physical principles.

X-rays and CT Scans: X-rays operate based on the principles of electromagnetic radiation. When X-rays pass through the body, different tissues absorb them at varying rates, allowing for the creation of images that reveal fractures, internal bleeding, or the presence of foreign objects. CT scans enhance this by combining multiple X-ray images to produce detailed cross-sectional views of the body, which are critical for assessing internal injuries (McSwain & Champion, 2013).

Magnetic Resonance Imaging (MRI): MRI technology is based on the principles of nuclear magnetic resonance. By aligning hydrogen atoms in the body using powerful magnets and radio waves, MRI machines generate detailed images of soft tissues. This is particularly valuable in assessing brain injuries, spinal cord damage, and other soft tissue injuries that are not as easily detected by X-rays or CT scans (Kalender, 2011).

Surgical Physics: Physics is also integral to surgical interventions, especially in trauma surgery. The use of lasers in surgery is based on the principles of optics and thermodynamics. Lasers allow for precise cutting and cauterization of tissues, minimizing blood loss and promoting faster recovery. Furthermore, an understanding of fluid dynamics is crucial during surgery, particularly in managing blood flow in cases involving severe hemorrhage (Hashemi, Bradley & Lisanti, 2012).

(ii) Rehabilitation and Recovery

Even after the initial trauma care, physics continues to influence the rehabilitation and recovery of trauma patients. The principles of biomechanics and the body's response to physical forces are essential in designing effective physical therapy programs.

(iii) Prosthetics and Orthotics: The design and application of prosthetics and orthotics are grounded in mechanics and material science. These devices are engineered to distribute forces in a manner that mimics natural movement, aiding in the patient's recovery and improving their quality of life (Van Leeuwan, Tuchin & Kalkman, 2011).

(iv) Therapeutic Modalities: Techniques such as ultrasound therapy and electrical stimulation used in physical rehabilitation are based on principles of sound waves and electrical conduction. These modalities are employed to reduce pain, enhance tissue healing, and improve muscle function (Fergason & Keeling, 2005).

Cross-Disciplinary Insights

To optimize trauma management, there is a need for interdisciplinary collaboration, which will aid in improving the development of more advanced protective gear and assistive devices for trauma patients. Integrating insights from biomechanics and material science can enhance trauma prevention (Yoganadan et al., 1996). For instance, advanced materials in helmets or body Armor, designed using energy absorption equation (8) play a crucial role in reducing injury by dissipating impact energy through controlled deformation of materials and structures, where U is the energy absorbed, F is the force applied, and dx is displacement of material (Lu & Yu, 2003).

$$U = \int F dx \qquad (8)$$

Global Perspective on Trauma Care

Trauma care techniques differ greatly depending on the area, mostly because of differences in infrastructure, medical technology availability, and resources access. Advanced trauma prevention technology such airbags and sophisticated protection gear may not be easily available in many low-resource environments. Simple mechanical ideas so become

extremely important for injury prevention and control. One important strategy in such situations is to limit injury severity by increasing the area across which force is applied to the body during traumatic incidence. This can be accomplished by adopting simple protective measures such as strengthened seatbelts or padded surfaces, which spread the force of contact across a broader surface area, minimizing strain on body tissues. This relationship is stated by the equation (3). This principle is supported by various studies that highlight the importance of pressure distribution in safety equipment (Chen, Wang & Cui, 2023).

Increasing *A* (the area) reduces *P* (the pressure) in low-resource settings, therefore helping to prevent trauma events or accidents' related injuries. For instance, conventional crash pads or cushions used in buildings and cars help to distribute the impact during an accident therefore reducing extreme trauma (Yang et al., 2022).

However, treating trauma in such environments usually calls for creative ideas that strike a mix between cost and efficacy. Low-cost but effective safety measures that may be generally adopted in areas where advanced technologies are not available should be the main emphasis of research and development.

Integrating a global perspective facilitates a comprehensive approach to trauma therapy, recognizing that universal physical principles exist, although their implementations must be tailored according to available resources. Initiatives to address this deficiency in trauma care can result in enhanced results, especially in resource-limited settings.

CONCLUSION

The Physics of trauma provides critical insights into how injuries occur and how they can be prevented. By applying principles of mechanics, energy transfer, momentum, and material science, we can better understand the mechanisms of injury and develop strategies for reducing the severity of trauma. As research in this field continues to evolve, advancements in injury prevention technologies will contribute to improving safety in various settings, from motor vehicles to sports and military operations. The application of Physics in trauma management is both extensive and critical at every stage, from the accident scene to the hospital and beyond. Moreover, with the knowledge of Physics, medical professionals can better assess injuries, stabilize patients, and apply the most effective diagnostic and therapeutic interventions. As medical technology continues to advance, the integration of Physics into trauma care will play an increasingly significant role in improving patient outcomes and saving lives.

REFERENCES

Brosing, J., & Griffith, W. T. (2021). *ISE physics of everyday phenomena* (6th ed.). McGraw-Hill Education

Bruna-Rosso, C., & Beauséjour, M. (2024). Modeling of cerebrospinal fluid for impact biomechanics. *Lecture Notes in Computational Vision and Biomechanics*, 242-249. https://doi.org/10.1007/978-3-031-55315-8_27

Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., & Boone, J. M. (2011). *The essential physics of medical imaging*. Lippincott Williams & Wilkins.

Chen, C., He, Z., Wang, X., & Cui, Y. (2023). Study on the pressure distribution of fall arrest belts in the static suspension and falling process. *Textile Research Journal*, *93*(23-24), 5307-5316. https://doi.org/10.1177/00405175231195895

Clark, E. M., Ness, A. R., & Tobias, J. H. (2008). Bone fragility contributes to the risk of fracture in children, even after moderate and severe trauma. *Journal of Bone and Mineral Research*, *23*(2), 173-179. https://doi.org/10.1359/jbmr.071010

Cooper, G. J. (1996). The biomechanics of ballistic injury. *Journal of Trauma and Acute Care Surgery, 40*(3), S41-S48.

Crandall, J. R., et al. (2013). Impact biomechanics: Responses of the head, neck, and spine to automotive collision scenarios. *Accident Analysis & Prevention, 58*, 81-90.

El-Qawaqzeh, K., Anand, T., Alizai, Q., Colosimo, C., Hosseinpour, H., Spencer, A., Ditillo, M., Magnotti, L. J., Stewart, C., & Joseph, B. (2024). Trauma in the geriatric and the super-geriatric: Should they be treated the same? *Journal of Surgical Research*, *293*, 316-326. https://doi.org/10.1016/j.jss.2023.09.015

Esenyel, M., Ozen, A., Esenyel, C. Z., Rezvani, A., Sariyildiz, M. A., & Ergin, O. (2011). Hip structural changes and fracture risk in osteopenia and osteoporosis. *The Eurasian Journal of Medicine*, *43*(2), 73-78. https://doi.org/10.5152/eajm.2011.17

Fergason, J. R., & Keeling, J. J. (2005). *Rehabilitation of the lower limb amputee*. In *Atlas of limb prosthetics: surgical, prosthetic, and rehabilitation principles*. American Academy of Orthopedic Surgeons.

Gennarelli, T. A., & Thibault, L. E. (1982). Biomechanics of acute subdural hematoma. *Journal of Trauma, 22*(8), 680-686.

Hall, N. J., & O'Toole, R. V. (2019). Physics of trauma and injury biomechanics. *British Journal of Surgery, 106*(9), 1112-1118.

Hashemi, R. H., Bradley, W. G., & Lisanti, C. J. (2012). *MRI: the basics*. Lippincott Williams & Wilkins.

Imam, S. A., Hughes, A. C., Carré, M. J., Driscoll, H., Winwood, K., Venkatraman, P., & Allen, T. (2023). Finite element model to simulate impact on a soft tissue simulant. *Sports Engineering*, *26*(1). https://doi.org/10.1007/s12283-023-00407-7

Kalender, W. A. (2011). *Computed tomography: fundamentals, system technology, image quality, applications*. Publicis Corporate Publishing

King, A. I., et al. (1979). Impact injury analysis of helmeted and unhelmeted motorcyclists. *Journal of Biomechanics, 12*(6), 507-515.

Lee, C. H., & Laksari, K. (2019). Cavitation in traumatic brain injury. *Journal of Biomechanics, 93,* 47-57.

Lissner, H. R., et al. (1960). The dynamic response of the human thorax to mechanical impact. *Journal of Clinical Investigation, 39*(8), 1191-1198.

Lu, G., & Yu, T. (2003). Composite materials and structures. *Energy Absorption of Structures and Materials*, 317-350. https://doi.org/10.1533/9781855738584.317

McElhaney, J. H., et al. (1976). Biomechanical injury mechanisms in lateral impacts. *Journal of Biomechanics, 9*(8), 459-470.

McSwain, N. E., & Champion, H. R. (2013). *Trauma care manual*. CRC Press

Nahum, A. M., & Melvin, J. W. (Eds.). (2002). *Accidental Injury: Biomechanics and Prevention*. Springer Science & Business Media.

Pankaj, P. (2013). Material properties of bone and fracture mechanics. *Current Opinion in Solid State and Materials Science, 17*(6), 308-314.

Riggs, B. L., Melton, L. J., Robb, R. A., Camp, J. J., Atkinson, E. J., Peterson, J. M., Rouleau, P. A., McCollough, C. H., Bouxsein, M. L., & Khosla, S. (2004). Population-based study of age and sex differences in bone volumetric density, size, geometry, and structure at different skeletal sites. *Journal of Bone and Mineral Research*, *19*(12), 1945-1954. https://doi.org/10.1359/jbmr.040916

Rudd, R. W., & Chawla, A. (2010). Biomechanics of fractures. *Journal of the Mechanical Behavior of Biomedical Materials, 3*(1), 93-102.

Seeman, E. (2008). Bone strength: The biomechanical basis of fracture risk. *Osteoporosis International, 19*(5), 519-522.

Stapp, J. P. (1963). Impact acceleration injury mechanisms. *Aerospace Medicine, 34*(11), 1069-1077.

Van Leeuwen, T. G., Tuchin, V. V., & Kalkman, J. (2011). *Handbook of optical coherence tomography*. CRC Press.

Yang, X., Shi, J., Fu, Q., Pu, S., Pan, Z., Lian, C., Yin, Z., Liu, S., & Wang, G. (2022). Optimization design and injury analysis of driver's restraint system in Sedan small offset collision. *Processes*, *10*(5), 940. https://doi.org/10.3390/pr10050940

Yoganandan, N., & Nahum, A. M. (2014). Biomechanics of trauma. *Biomechanics and Modeling in Mechanobiology*, *13*(2), 217-232.

Yoganandan, N., Pintar, F. A., Kumaresan, S., Hargarten, S., & Sances, A. (1996). Dynamic biomechanics of penetrating trauma. *Advances in Bioengineering*, 41-42.