MATHEMATICAL FOUNDATION OF BIOMECHANICS

Babita Bist

Abstract

Biomechanics has numerous connections and overlapping areas with biology, biochemistry, physiology so its range is enormously wide but Its foundations are basically in mathematics, physics, and informatics. Like other sciences, biomechanics also uses basic and complex mathematics to study the movement and motion of living things. This paper presents some of mathematical concepts frequently used in biomechanics like trigonometry, vector analysis, co-ordinate geometry, measurements, statics, dynamics, forces and moments.

Introduction

Biomechanics has been defined as the study of the movement of living things using the science of mechanics. It is the analysis of the structure and function of humans, animals, and plants by means of the methods of mechanics. Mechanics is a branch of physics and applied mathematics that is concerned with the description of motion and how forces create motion. Forces acting on living things can create motion, be a healthy stimulus for growth and development, or overload tissues, causing injury. Biomechanics provides conceptual and mathematical tools that are necessary for understanding how living things move and improve movement or make movement safer to reduce the risk of injury.

Mathematical formulas are a precise language and are most helpful in showing the importance, interactions, and relationships between biomechanical variables. While more rigorous calculus forms of these equations provide the most accurate answers commonly used by scientists. Biomechanics often uses some of the most complex kinds of mathematical calculations, especially in deformable-body mechanics. Basic mathematics required to study the biomechanics involve unit of measurement, trigonometry, vector analysis, forces, statics, dynamics, co-ordinate geometry etc.

Units of Measurement

Measurements must be accompanied by a unit to have any physical meaning. Sometimes, there are situations when certain units are assumed. If someone asks for height and the reply is "5-6," it can reasonably be assumed that the person is 5 feet, 6 inches tall. However, that interpretation would be inaccurate if we are in Europe, where the metric system is used. There are also situations where the lack of a unit makes a number completely useless. If a person was told to perform a series of exercises for two, he would have no idea if that meant two days, weeks, months, or even years.

Trigonometry

Since angles are so important in the analysis of the musculoskeletal system. So trigonometry is a very useful biomechanics tool. The accepted unit for measuring angles is degree. Trigonometric functions are very useful in biomechanics for resolving forces into their components by relating angles to distances in a right triangle. Some of applications in biomechanics include

- Find a distance or displacement given a set of coordinates
- Analyze projectile motion(baseball, discus, javelin, basketball etc.)
- Find the net force acting on an object or body segment
- Separate muscle force into a component causing movement and a component affecting joint stability

Vector Analysis

Biomechanical parameters can be represented as either scalar or vector quantities. Consider the situation of a 120-lb man sitting in a chair for 20 seconds. The force that his weight is exerting on the chair is represented by a vector with magnitude (120 lb), direction (downward), orientation (vertical), and point of application (the chair seat). However, the time spent in the chair is a scalar quantity and can be represented by its magnitude (20

seconds).

The most common use of vectors in biomechanics is to represent forces, such as muscle, joint reaction and resistance forces. These forces can be represented graphically with the use of a line with an arrow at one end. The length of the line represents its magnitude, the angular position of the line represents its orientation, the location of the arrowhead represents its direction, and the location of the line in space represents its point of application. Alternatively, this same vector can be represented mathematically with the use of either polar co-ordinate. When studying musculoskeletal biomechanics, it is common to have more than one force to consider. Therefore, it is important to understand how to work with more than one vector. When adding or subtracting two vectors, there are some important properties to consider.

Coordinate Systems

A three-dimensional analysis is necessary for a complete representation of human motion. Two commonly used coordinate systems in biomechanics are the Cartesian coordinate system and the polar coordinate system. The Cartesian coordinate system is perhaps the most commonly used system in biomechanics. It provides a unique advantage in terms of consistency and simplicity. Unfortunately, not all biomechanical problems are well adapted to solution in Cartesian coordinate system. Therefore the coordinate system should be chosen to fit the problem so that it becomes more readily soluble.

It is often convenient to consider only a two-dimensional system in which only two of the three axes are considered. The motion of any bone can be considered with respect to either a local or global coordinate system. For example, the motion of the tibia can be described by how it moves with respect to the femur (local coordinate system) or how it moves with respect to the room (global coordinate system). Local coordinate systems are useful for understanding of joint function and range of motion, while global coordinate systems are useful for functional activities. Most of time focus remains on two-dimensional analysis because it is difficult to display three-dimensional information on two-dimensional pages of a book. Also, the mathematical analysis for a three dimensional problem is very complex. Perhaps the most important reason is that the fundamental biomechanical principles in a two-dimensional analysis are the same as those in a three-dimensional analysis. It is therefore possible to use a simplified two-dimensional form of a three-dimensional problem to help explain a concept with minimum mathematical complexity (or at least less complexity).

STATICS

Statics is the study of the forces acting on a body at rest or moving with a constant velocity. Although the human body is almost always accelerating, a static analysis offers a simple method of addressing musculoskeletal problems. This analysis may either solve the problem or provide a basis for a more sophisticated dynamic analysis.

The musculoskeletal system is responsible for generating forces that move the human body in space as well as prevent unwanted motion. Understanding the mechanics of human motion requires an ability to study the forces and moments applied to, and generated by, the body or a particular body segment. A force is defined as a "push or pull" that results from physical contact between two objects. The only exception to this rule that is considered is the force due to gravity, in which there is no direct physical contact between two objects. Some of the more common force generators with respect to the musculoskeletal system include muscles/ tendons, ligaments, friction, ground reaction, and weight. A distinction must be made between the mass and the weight of a body. The mass of an object is defined as the amount of matter composing that object. The weight of an object is the force acting on that object due to gravity and is the product of its mass and the acceleration due to gravity. So while an object's mass is the same on Earth as it is on the moon, its weight on the moon is less, since the acceleration due to gravity is lower on the moon. This distinction is important in biomechanics for ensuring that a unit of mass is not treated as a unit of force. As mentioned previously, force is a vector quantity with magnitude, orientation, direction, and a point of application.

Conclusion

In the field of biomechanics the laws of mechanics are applied to gain better performance and to reduce risk of injury through mathematical knowlede, mathematical modelling, computer simulation and measurement.

References

1. Vriesd.W.H.K. et. al. (2010), "Functionally interpretable local coordinate systems for the upper extremity using inertial & magnetic measurement systems", Journal of Biomechanics, Volume 43, Issue 10, Pages 1983-1988.

2. Takahashi An. K.N. et. al. (1997), "Electromyography of shoulder muscles in relation to force direction"' J Shoulder Elbow Surg, 6: 360–370.
3. Chao E.Y. (1993), "Simulation and animation of musculoskeletal joint system", J Biomech Eng, 115: 562–568.
4. Karduna A.R. (2012), "Understanding the Biomechanical Nature of Musculoskeletal Tissue", Journal Of Hand Therapy, 25:116–22.
5. Fuller J.J. and Winters J.M. (1993), "Assessment of 3-D joint contact load preditions during postural/stretching exercises in aged females", Ann Biomed Eng, 21: 277–288.
6. Laursne B. et. al. (1998), "A model predicting individual shoulder muscle forces based on relationship between electromyographic and 3D external forces in static position", J Biomech, 31: 731–739.
7. LeVeau B.F. et.al. (1992), "Biomechanics of Human Motion", 3rd ed. Philadelphia.