An Engineering Perspective on the Biomechanics and Bioelectricity of Fishes

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Abstract

Fish biomechanics and bioelectricity are fascinating subjects that have attracted researchers from various disciplines. Fish possess unique adaptations that allow them to move and maneuver efficiently in aquatic environments, and to produce and utilize electric fields for multiple purposes. Recent developments in these areas of study are explored in this review, with an overview of the current state of knowledge in these fields. Mathematical models have been utilized by researchers to gain insights into the mechanisms responsible for fish movement and propulsion, leading to a better understanding of the complex mechanisms that enable fish to generate powerful and precise movements, allowing them to swim and maneuver efficiently. The study of fish biomechanics has also inspired the development of new underwater propulsion systems, with applications in both military and industrial settings.In the field of fish bioelectricity, researchers have focused on understanding the mechanisms behind the production of electric fields by fish, and their roles in a variety of physiological and behavioral processes, such as predator avoidance, prey detection, and communication. The study of fish electrogenesis has also led to the development of new electrotherapy techniques for the treatment of various medical conditions. In summary, this review provides an overview of the current state of knowledge in the fields of fish biomechanics and bioelectricity, highlighting the importance of these areas of study for understanding these remarkable animals and developing new technologies and applications.

Keywords: Electro-Receptors; Electro-Therapy; Icthyo-Electricity; Icthyo-Mechanics; Mathematical Modelling.

Introduction

Fish are highly diverse and adaptable aquatic creatures that play an essential role in the food chain **(Stevens et al., 2000)**. Although there is still much to learn about fish biomechanics and bioelectricity, these fields are crucial to understanding the evolutionary history of fish and their role in aquatic ecosystems. Biomechanics is the study of the mechanics of living organisms and their movements. In fish, this field aims to understand the physical principles that govern swimming and movement, which are primarily driven by the muscular and skeletal systems **(Lutek et al., 2022)**. Fish have unique adaptations, such as a streamlined body shape, a dorsal fin for stability, and a flexible tail for propulsion, as well as a swim bladder that allows them to control their buoyancy. Fish also use undulatory movements to generate propulsion, such as using their pectoral fins or tail. Bioelectricity, on the other hand, studies the electrical signals produced by living organisms. Fish use electrocytes to generate electrical signals, such as the electric organ discharge (EOD) for communication and prey detection and the lateral line system to detect changes in water pressure **(Webb., 1984; Yu et al., 2019)**. These mechanisms are essential for fish to navigate, communicate, and locate prey, even in limited visibility or murky waters. As research in fish biomechanics and bioelectricity continues to progress, we can expect to gain a deeper understanding of the mechanisms behind fish swimming and their crucial role in aquatic ecosystems **(Martin., 2007)**. This article provides an exploratory review of the current state of knowledge in these fields and highlights the challenges and future directions for research.

Mechano-Electrical Understanding of Fishes: Musculoskeletal System

Fishes have a complex musculo-skeletal system that enables them to swim, hunt, and escape from predators. The anatomy and physiology of the system play a crucial role in the survival and adaptation of fish in their aquatic environments. The skeleton of a fish is composed of a combination of bony and cartilaginous tissues, providing support, protection, and a framework for the muscles to attach to. Fish have a flexible spinal column that allows for efficient movement, and their fins serve as powerful propulsion devices **(Weihs., 1989)**. The dorsal fin, in particular, helps maintain stability and balance, while the caudal fin provides the main source of propulsion. Fishes muscles can be divided into two categories, white and red. White muscles are used for sudden bursts of speed and movement, while red muscles are used for sustained swimming and other activities that require endurance. These muscles work together to control the movement of the fins, tail, and other body parts, enabling the fish to swim in different directions and at various speeds **(Wolf et al., 2020)**. The musculo-skeletal system of fish is closely linked to the nervous system. Nerve impulses from the brain and spinal cord coordinate the contraction and relaxation of the muscles, allowing the fish to respond quickly to changes in its environment. This system also enables fish to sense their surroundings, detect prey, and avoid predators. The anatomy and physiology of the fish musculo-skeletal system are closely related to the type of environment in which the fish lives. For example, deep-sea fish have larger fins and a more streamlined body shape than shallow water species, enabling them to swim effectively in the strong currents of the deep ocean. Similarly, some species of fish that live in fast-moving rivers have evolved powerful muscles and fins that allow them to swim against the current. The anatomy and physiology of the fish musculo-skeletal system play a vital role in their survival and adaptation to different aquatic environments. Through the combination of bony and cartilaginous skeletons, powerful muscles, and a highly developed nervous system, fish are able to move effectively and respond to changes in their environment.

The muscular anatomy of fish plays a critical role in the production of biomechanical effects, contributing to their ability to swim, hunt, and evade predators **(Voesenek et al., 2018)** . Understanding the structure and function of fish muscles is essential for understanding the anatomy and physiology of fish, and is important for several fields including aquaculture, fish biology, and the development of fishing gear and techniques. Fish muscles can be broadly divided into two categories: white and red. White muscles are used for sudden, short bursts of speed, such as jumping or escaping from predators. They are composed of fast-twitch fibers and contain a high proportion of glycogen, which is converted into glucose to provide energy. Red muscles are used for sustained swimming and other activities that require endurance. They are composed of slow-twitch fibers and contain a higher proportion of myoglobin **(Jin et al., 2022)**, which stores oxygen and provides energy for longer periods of time. The muscles of fish are attached to the skeleton by tendons, allowing them to contract and relax, resulting in movement. The muscles of fish are also specialized to produce different types of movement, such as swimming, jumping, or biting. The muscles responsible for swimming are primarily located in the trunk, tail, and fins. The swimming muscles are controlled by nerve impulses from the spinal cord and brain, enabling the fish to coordinate movement and respond to changes in its environment. The muscles of fish play a significant role in the biomechanics of swimming. Fish have developed a variety of swimming styles, each of which is optimized for different environments and behaviours **(Blake., 2004)**. For example, some fish species have developed powerful muscles and fins to swim against strong currents, while others have evolved to swim quickly to catch prey. The anatomy and physiology of fish muscles are closely related to the type of swimming style, with different species having different muscle arrangements to produce specific types of movement **(**see **Figure 1)**. Fish muscles also play a role in the production of hydrodynamic forces, which are essential for swimming. The movement of fish through water generates lift, drag, and thrust forces, which can be controlled by the contraction and relaxation of the muscles. For example, the caudal fin is the primary source of propulsion for fish, and the contraction of the tail muscles generates thrust, which propels the fish through the water. The muscular anatomy of fish is a critical component of the production of biomechanical effects **(**see **Figure 1)**. Fish muscles enable them to swim, hunt, and evade predators, and are specialized to produce different types of movement and hydrodynamic forces **(Wardle., 1986)**. Understanding the structure and function of fish muscles is important for several fields, including aquaculture, fish biology, and the development of fishing gear and techniques. The anatomy and physiology of fish muscles are closely related to the type of environment in which the fish lives and the specific behaviors it engages in.

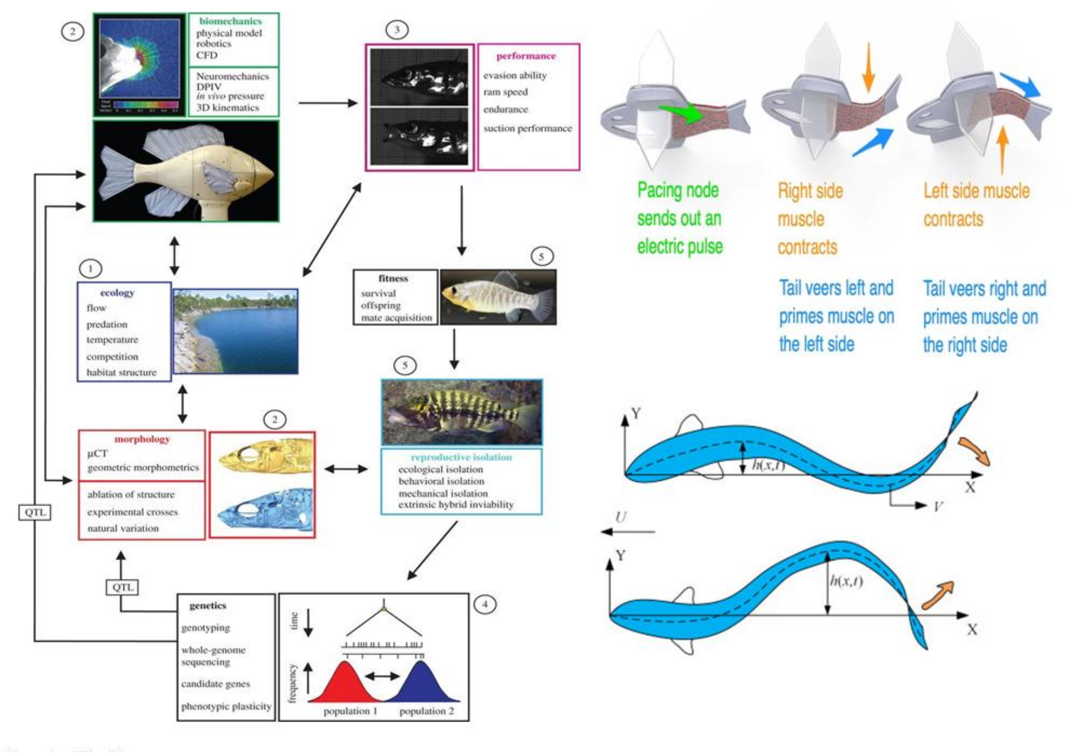


Figure 1. Fish Biomechanics related to locomotion and other physiological impacts.

Fish possess a unique and complex muscular anatomy that plays a crucial role in producing bioelectric effects. These bioelectric signals are produced by the contraction and relaxation of muscle fibers and are used for a variety of functions including communication, navigation, and hunting. Understanding the anatomy and physiology of fish muscles is essential for understanding the bioelectric signals they produce and their role in the behavior and survival of fish. Fish muscles are comprised of both fast-twitch and slow-twitch fibers, which are specialized to produce different types of movements **(**see **Figure 1)**. Fast-twitch fibers are used for sudden, short bursts of speed, such as jumping or escaping from predators, while slow-twitch fibers are used for sustained swimming and other activities that require endurance. The muscles of fish are also connected to the nervous system through nerves, allowing them to respond to changes in their environment and coordinate movement. Fish muscles play a critical role in the production of bioelectric signals. These signals are produced by the contraction and relaxation of muscle fibers and are used for a variety of functions, including communication, navigation, and hunting. For example, fish use bioelectric signals for communication, emitting low-frequency electric signals to attract mates, establish territory, or deter predators. Some species of fish, such as the electric eel and the electric catfish, have evolved specialized muscles that produce high-voltage bioelectric signals for hunting and defense**(Compagno ., 1990)**. The anatomy and physiology of fish muscles are closely related to the type of bioelectric signals they produce. Some species of fish have evolved specialized muscle arrangements to produce specific types of bioelectric signals. For example, the electric eel has a specialized muscle that produces high-voltage bioelectric signals for hunting, while the electric catfish has a specialized muscle for defense. The muscular anatomy of fish plays a critical role in the production of bioelectric effects. The contraction and relaxation of muscle fibers produce bioelectric signals that are used for communication, navigation, and hunting. Fish muscles are specialized to produce different types of bioelectric signals, and their anatomy and physiology are closely related to the specific behaviors and functions they serve. Understanding the anatomy and physiology of fish muscles is essential for understanding the bioelectric signals they produce and their role in the behavior and survival of fish.

Understanding the Physiology of Icthyomechanics via Mathematical Modeling

Mathematical physiology of biomechanics is the study of the mathematical modeling and analysis of biological systems and how they produce biomechanical effects. It is a interdisciplinary field that combines mathematics, physiology, and biomechanics to understand the mechanical behavior of living organisms. The mathematical models developed in this field provide insights into the functioning of biological systems and enable predictions of biomechanical effects. One of the central goals of mathematical physiology of biomechanics is to develop mathematical models that describe the behavior of biological systems. These models typically involve a combination of partial differential equations, ordinary differential equations, and/or difference equations. The models are derived from the underlying physiological processes, including the mechanics of cells, tissues, and organs, and the biochemical and physiological processes that regulate these mechanics **(Crampin et al., 2004)**. The models are then analyzed and simulated to understand the behavior of the biological system and the mechanisms underlying biomechanical effects. There are several types of mathematical models used to study the movement and locomotion of fish. These models help to understand the mechanics and energetics of fish movement and provide insight into the factors that influence their swimming behavior. Some of the most commonly used models in fish movement and locomotion analysis include:

- Kinematic models: These models describe the movement of fish in terms of the displacement, velocity, and acceleration of their body segments. The models are based on observations of fish swimming behavior and are used to quantify the motion of fish in a laboratory setting.
- Hydrodynamic models: These models describe the fluid mechanics of fish swimming, including the forces and torques generated by the fish's body and fins. The models are used to study the interaction between fish and their fluid environment and

to understand the energy costs and efficiency of fish swimming.

- Muscle activation models: These models describe the patterns of muscle activation during fish swimming, including the timing and duration of muscle contractions and the distribution of force across different muscle groups. The models are used to study the coordination of muscle activity during swimming and to understand the mechanisms underlying the control of fish movement.
- Energetics models: These models describe the metabolic cost of fish swimming, including the energy expenditure required to generate the forces and torques needed for movement. The models are used to study the efficiency of fish swimming and to understand the trade-offs between speed and endurance in different swimming behaviors.
- Optimal control models: These models use mathematical optimization techniques to find the most energy-efficient way for a fish to swim in a given environment. The models are used to study the influence of different environmental factors, such as water flow and temperature, on fish swimming behavior.

The study of fish movement and locomotion utilizes a range of mathematical models, each of which provides a different perspective on the mechanics and energetics of fish swimming. The models are used to study the kinematics, hydrodynamics, muscle activation, energetics, and optimal control of fish movement and provide insights into the factors that influence their behaviour **(Lauder & Di Santo ., 2015)**.

Understanding the Physiology of Icthyoelectricity via Mathematical Modeling

Mathematical physiology of ichthyoelectricity refers to the study of the electrical signals produced by fish, and how these signals are used for communication and navigation. The field combines mathematical modeling, physiology, and electrophysiology to understand the mechanisms and functions of ichthyoelectricity**(Maruska&Sisneros ., 2016)**. Fish are able to produce electrical signals by means of specialized cells called electrocytes, which are located in the electric organs of some species of fish. These electrical signals serve a variety of functions, including communication, navigation, and prey detection. The signals are generated by the depolarization and repolarization of the electrocytes and are transmitted through the water to other fish or objects in the environment. Mathematical models of ichthyoelectricity provide a framework for understanding the mechanisms underlying electrical signal generation and transmission in fish. The models are based on the principles of electrophysiology and describe the flow of electrical currents through the electrocytes and surrounding tissues **(Haehnel-Taguchi et al., 2018)**. The models are used to study the factors that influence the electrical signals produced by fish, such as the size and distribution of the electrocytes, the conductivity of the surrounding tissue, and the environmental conditions. The mathematical models are also used to study the ways in which fish use ichthyoelectricity for communication and navigation. For example, the models can be used to study the way in which fish use electrical signals to locate other fish or objects in their environment, and the ways in which they use electrical signals to communicate with each other. The models can also be used to study the effects of environmental factors, such as water temperature and salinity, on the electrical signals produced by fish. Mathematical physiology of ichthyoelectricity is a rapidly growing field that combines mathematical modeling, physiology, and electrophysiology to understand the mechanisms and functions of ichthyoelectricity. The mathematical models developed in this field provide a framework for understanding the generation and transmission of electrical signals in fish and the ways in which these signals are used for communication and navigation. The field has important implications for our understanding of fish behavior and ecology, and has the potential to inform the development of new technologies for monitoring and managing aquatic ecosystems. There are several types of mathematical models used to study the generation of bioelectricity in fish. These models provide a framework for understanding the mechanisms underlying electrical signal generation and transmission in fish and the ways in which these signals are used for communication and navigation **(Tomita ., 1965)**. Some of the most commonly used models in fish bioelectricity generation study include:

- Electrocyte models: These models describe the electrical properties of the electrocytes, which are specialized cells located in the electric organs of some species of fish. The models are used to study the depolarization and repolarization of the electrocytes and the flow of electrical currents through these cells.
- Circuit models: These models describe the electrical circuits formed by the interactions between the electrocytes and other tissues in the fish body. The models are used to study the flow of electrical currents through the fish body and the way in which these currents are used for communication and navigation.
- Source-field models: These models describe the electrical signals generated by the fish and the way in which these signals propagate through the surrounding water. The models are used to study the effects of environmental factors, such as water temperature and conductivity, on the electrical signals produced by fish.
- Electrophysiological models: These models describe the underlying electrophysiology of the fish, including the mechanisms of signal generation and transmission, the role of ion channels, and the regulation of electrical signaling. The models are used to study the physiological and molecular mechanisms underlying

electrical signal generation and transmission in fish.

- Bioenergetics models: These models describe the metabolic cost of electrical signal generation and transmission, including the energy expenditure required to generate the electrical signals and the ways in which energy is conserved during electrical signaling. The models are used to study the efficiency of electrical signal generation and transmission and the trade-offs between energy expenditure and signal transmission distance.

Mathematical models play a critical role in the study of fish bioelectricity generation. The models provide a framework for understanding the mechanisms underlying electrical signal generation and transmission and the ways in which these signals are used for communication and navigation. The models also inform the development of new technologies for monitoring and managing aquatic ecosystems.

Bioelectric Field Patterns and Bioelectro-receptors

Fish possess specialized sensory organs called electroreceptors that allow them to detect and respond to electrical signals in their environment. These electroreceptors are found in various regions of the fish body, including the head, body, and fins. The distribution of electroreceptors, the patterns of the bioelectric field they produce, and the skin resistance of the fish play important roles in the ability of fish to detect and respond to electrical signals in their environment. The distribution of electroreceptors in fish is highly variable and depends on the species and the specific ecological niche in which it lives **(Atema .,1980)**. For example, some species of fish have dense clusters of electroreceptors in their head region, which are used for prey detection and navigation. Other species have more dispersed electroreceptors, which are used for communication and navigation. The bioelectric field patterns produced by fish are also highly variable and depend on the species and the specific electrical signals being produced. For example, some species of fish produce pulsed electrical signals for communication, while others produce continuous signals for navigation. The bioelectric field patterns produced by fish are determined by the distribution of electrocytes and the flow of electrical currents through these cells **(**see **Figure 2)**. The skin resistance of fish also plays an important role in the ability of fish to detect and respond to electrical signals in their environment. The skin resistance of fish affects the electrical signals produced by the fish and the way in which these signals propagate through the surrounding water. Fish with high skin resistance are able to generate and transmit stronger electrical signals, while those with low skin resistance are more sensitive to weak electrical signals in their environment. Distribution of electroreceptors, bioelectric field patterns, and skin resistance play important roles in the ability of fish to detect and respond to electrical signals in their environment. The highly variable distribution of electroreceptors, bioelectric field patterns, and skin resistance among different species of fish reflects the diverse ways in which fish use electrical signals for communication, navigation, and prey detection. Understanding the distribution, patterns, and resistance of electroreceptors in fish is crucial for our understanding of fish behavior and ecology and has important implications for the conservation and management of aquatic ecosystems **(Rother et al., 2003)**. Fish have specialized sensory structures known as electroreceptors that allow them to detect electrical signals in their environment. These electroreceptors play important roles in communication, navigation, and prey detection in fish. There are several types of electroreceptors in fish, including:

- Ampullary electroreceptors: Ampullary electroreceptors are located in the lateral line system of fish and are used to detect low-frequency electrical signals in the environment. These electroreceptors are found in large numbers in fish and play important roles in navigation and communication.
- Tuberous electroreceptors: Tuberous electroreceptors are located on the head and body of fish and are used to detect high-frequency electrical signals. These electroreceptors play important roles in prey detection and communication.
- Trigeminal electroreceptors: Trigeminal electroreceptors are located in the head of fish and are used to detect weak electrical signals generated by the movement of prey. These electroreceptors play important roles in prey detection and foraging behavior.
- Photoreceptor cells: Photoreceptor cells are located in the eye of fish and are used to detect light. Some species of fish also have specialized photoreceptor cells that are sensitive to ultraviolet light. These photoreceptor cells play important roles in communication and navigation.

There are several types of electroreceptors in fish that play important roles in communication, navigation, and prey detection. These electroreceptors allow fish to detect electrical signals in their environment and to respond appropriately to these signals. The diversity of electroreceptors observed among different species of fish reflects the wide range of ecological niches occupied by these species and the diverse ways in which they use electrical signals to interact with their environment **(Kempster et al., 2012)**.

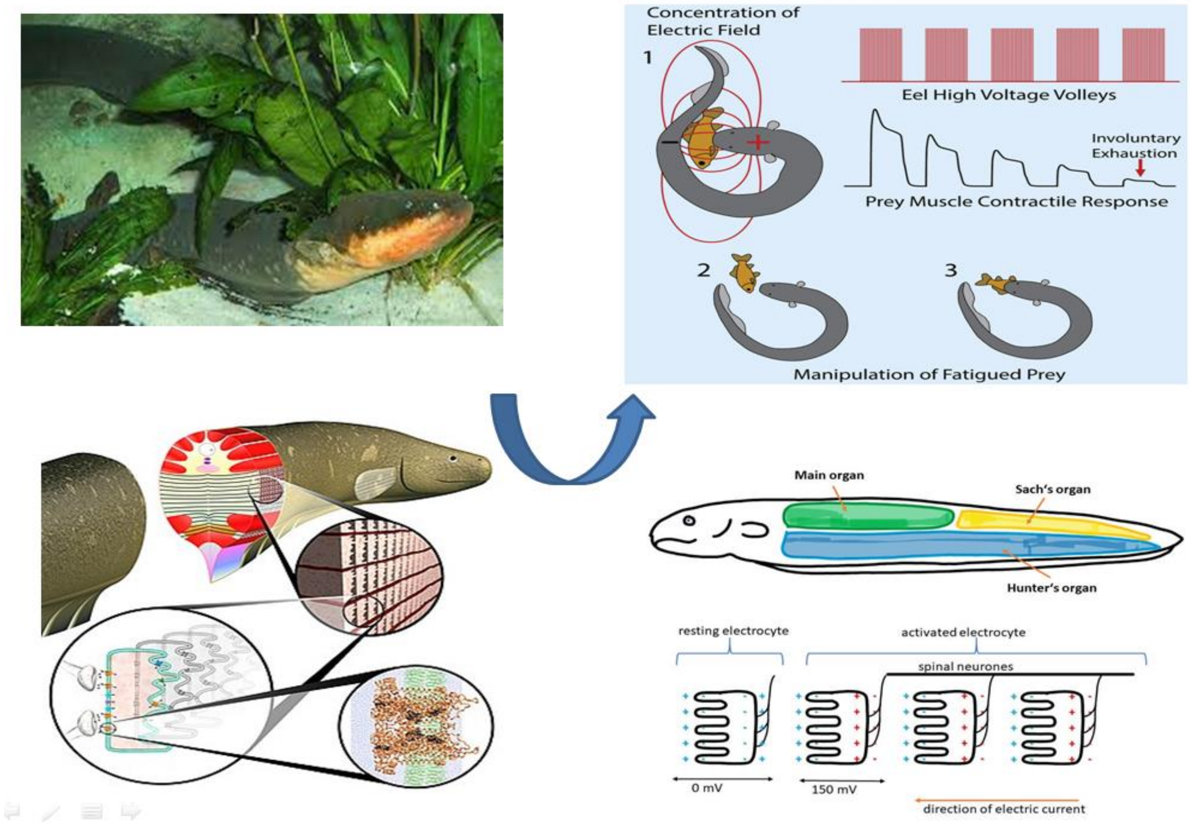


Figure 2. Bioelectricity production in eels to attack and capture prey

There are several types of bioelectric field patterns produced by fish in response to different stimuli in their environment. These bioelectric field patterns play important roles in the ability of fish to detect and respond to electrical signals for communication, navigation, and prey detection. Some of the most commonly observed types of bioelectric field patterns in fish include:

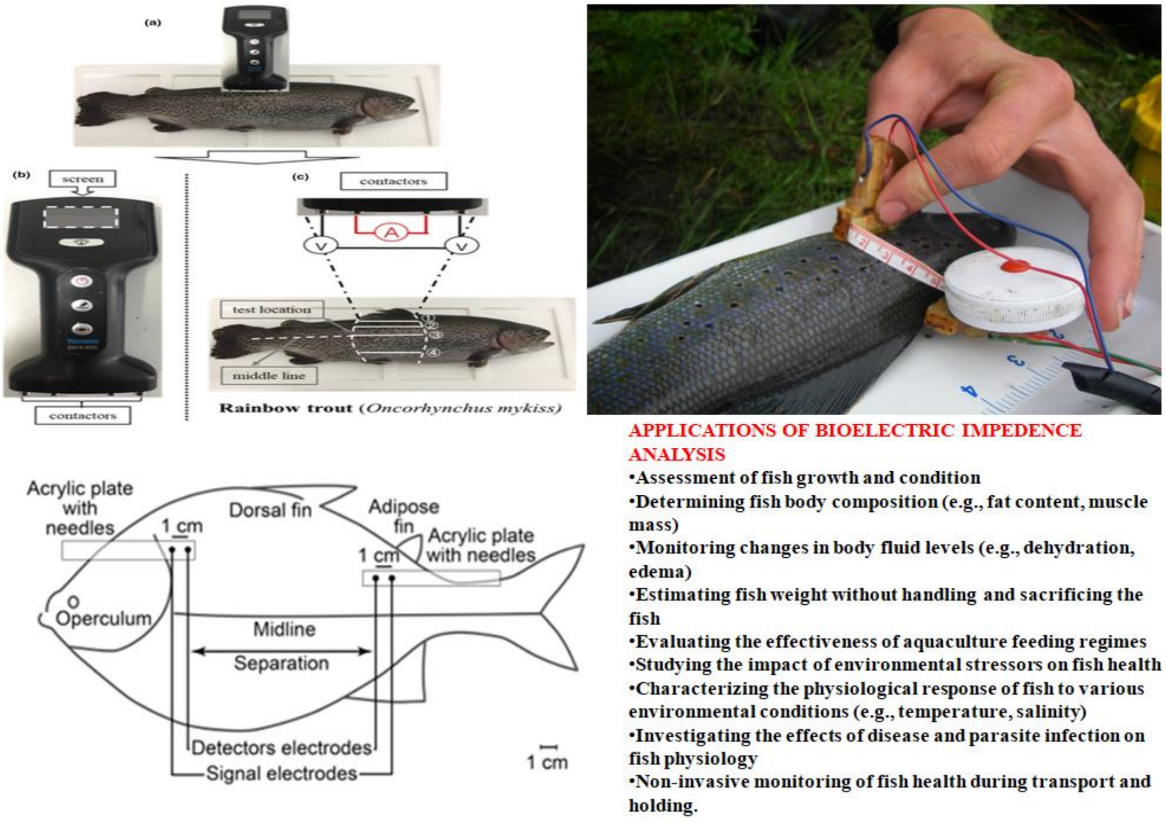
- Pulsed signals: Pulsed signals are brief electrical signals that are emitted in rapid succession. These signals are used by fish for communication and prey detection. Pulsed signals are highly variable in terms of their frequency, duration, and waveform.
- Continuous signals: Continuous signals are electrical signals that are maintained at a constant level for an extended period of time. These signals are used by fish for navigation and communication. Continuous signals are typically low frequency and have a constant waveform.
- Modulated signals: Modulated signals are electrical signals that are altered in response to changes in the environment or the behavior of the fish. Modulated signals are used by fish for communication and navigation and typically involve changes in the frequency, amplitude, or waveform of the electrical signals.

- Dorsal fin signals: Dorsal fin signals are electrical signals that are generated by the movement of the dorsal fin of the fish. These signals are used for communication and navigation and are typically highly directional.
- Burst signals: Burst signals are brief, high-amplitude electrical signals that are emitted in rapid succession. These signals are used by fish for communication and prey detection and are typically highly directional.

There are several types of bioelectric field patterns produced by fish in response to different stimuli in their environment. These bioelectric field patterns play important roles in the ability of fish to detect and respond to electrical signals for communication, navigation, and prey detection **(Crampton ., 2019)**. The diversity of bioelectric field patterns observed among different species of fish reflects the wide range of ecological niches occupied by these species and the diverse ways in which they use electrical signals to interact with their environment.

Study of Bioelectric Impedance

Bioelectrical Impedance Analysis (BIA) is a non-invasive technique used to assess body composition and fluid distribution in living organisms. It is based on the principle that electrical signals flow differently through different tissues in the body and can be used to determine the impedance, or resistance to the flow of electrical current, of these tissues. BIA has been widely used in human medicine for the assessment of body composition and fluid distribution, but it has also been applied to the evaluation of body composition in fish **(Hartman et al., 2015)**. The evaluation of BIA in fish involves the measurement of electrical impedance across a specific frequency range. The impedance data is then used to calculate the resistance and reactance of the tissues and the distribution of body water in the fish. BIA has several advantages over other methods of body composition analysis, including its non-invasive nature, its ease of use, and its ability to provide rapid results. One of the main advantages of BIA in fish is its ability to provide a comprehensive assessment of body composition, including the measurement of fat, muscle, and bone mass **(Pothoven et al., 2008)**. This information is critical for understanding the energy budget and nutritional status of fish, as well as for evaluating the impact of environmental stressors on the health and survival of these species. BIA can also be used to monitor the changes in body composition that occur during growth and maturation, and to evaluate the effects of different diets and feeding regimes on body composition **(**see **Figure 3)**. Another advantage of BIA in fish is its ability to provide information on fluid distribution in the body. This information is critical for understanding the effects of environmental stressors, such as temperature and salinity changes, on the health and survival of fish. BIA can also be used to monitor the changes in fluid distribution that occur during growth and maturation, and to evaluate the effects of different diets and feeding regimes on fluid distribution in the body. BIA is a valuable tool for the evaluation of body composition and fluid distribution in fish. Its non-invasive nature, ease of use, and ability to provide rapid results make it an attractive option for researchers and resource managers interested in understanding the health and biology of fish populations. The information obtained from BIA can be used to evaluate the impact of environmental stressors on fish populations, to monitor changes in body composition and fluid distribution during growth and maturation, and to evaluate the effects of different diets and feeding regimes on the health and survival of fish **(Caldarone et al., 2012)**.



APPLICATIONS OF BIOELECTRIC IMPEDENCE ANALYSIS

- **Assessment of fish growth and condition**
- **Determining fish body composition (e.g., fat content, muscle mass)**
- **Monitoring changes in body fluid levels (e.g., dehydration, edema)**
- **Estimating fish weight without handling and sacrificing the fish**
- **Evaluating the effectiveness of aquaculture feeding regimes**
- **Studying the impact of environmental stressors on fish health**
- **Characterizing the physiological response of fish to various environmental conditions (e.g., temperature, salinity)**
- **Investigating the effects of disease and parasite infection on fish physiology**
- **Non-invasive monitoring of fish health during transport and holding.**

Figure 3. Bioelectric impedance analysis applications in fishes

Fish Generating Hazardous Electricity at High Voltage

Dangerous electric fishes are species of fish that can produce strong electric fields for self-defense and for the detection of their prey **(**see **Figure 4)**. These electric fields are generated by specialized cells known as electrocytes, which are capable of generating and maintaining electric potentials **(**see **Table 1)**. The functioning of cells in dangerous electric fishes is a complex process that involves the integration of various physiological and biochemical processes. The electrocytes in dangerous electric fishes are unique cells that are specialized for the production of electric fields. These cells are packed with membrane channels that allow ions to flow into and out of the cell, generating an electric potential. The electrocytes in dangerous electric fishes are capable of producing electric fields of high amplitude and duration, making them effective for both self-defense and prey detection **(Stoddard et al., 2019)**. The production of electric fields in dangerous electric fishes is regulated by complex physiological processes, including the regulation of ion flow, membrane potential, and metabolic activity. These processes are controlled by specialized nerve cells known as electrocyte control neurons, which coordinate the activity of the electrocytes to produce the desired electric field.

In addition to the specialized cells and nerve cells involved in electric field generation, dangerous electric fishes also have specialized sensory structures that allow them to detect electric fields in their environment. These sensory structures are known as electroreceptors, and they are highly specialized for the detection of weak electric fields. Electroreceptors play a critical role in the hunting and feeding behavior of dangerous electric fishes, allowing them to detect and track their prey **(Markham et al., 2009)**. The functioning of cells in dangerous electric fishes is a complex and sophisticated process that involves the integration of various physiological and biochemical processes. The specialized cells, nerve cells, and sensory structures involved in electric field generation and detection allow these fishes to effectively use electric fields for self-defense and prey detection. The study of dangerous electric fishes provides valuable insights into the mechanisms of electric field generation and the role of electric fields in the biology of these unique and fascinating species.

Table1: List of Danger electric fishes with generatedElectric voltage (Note: These estimates may vary and depend on a number of factors, such as species, size, and environmental conditions. Additionally, these voltages are not constant, as they can vary depending on the animal's behavior and physiological state.)

SI.No.	Electric Fish Name	Estimated Electric voltage
1	Electric Eel (*Electrophorus electricus*)	600 volts
2	Knife Fish (*Gymnotus spp.)*	100-800 volts
3	Catfish (*Malapteruruselectricus*)	350 volts
4	Electric Ray (*Torpedo spp.*)	50-220 volts
5	Stingray (*Dasyatisamericana*)	50 volts
6	Electric Catfish (*Malapterurus spp.*)	70 volts
7	African electric catfish (*Malapterurusmicrostoma*)	600 volts
8	African electric eel (*Gymnarchusniloticus*)	400 volts
9	Black Ghost Knife Fish (*Apteronotusalbifrons*)	30 volts
10	Electric stargazer (*Uranoscopus spp.*)	50 volts

Figure 4. Dangerous Electric fishes

Employing Fish Bioelectricity in Electrotherapy

Fish bioelectricity has been recognized as a valuable resource for the development of new therapeutic techniques in medicine. Bioelectricity refers to the electrical signals generated by living organisms, including fish. In recent years, the study of fish bioelectricity has led to the development of electrotherapy, a novel therapeutic technique that uses electrical stimulation to treat various medical conditions. Electrotherapy has been used in humans for the treatment of a wide range of medical conditions, including pain, inflammation, and muscle spasms. The use of electrotherapy in fish is based on the principle that electrical stimulation can have therapeutic effects on the tissues of the body **(Zago et al., 2021)**. The electrical stimulation used in electrotherapy is delivered through electrodes that are placed on the skin or in close proximity to the affected area. Fish bioelectricity has several unique properties that make it well suited for use in electrotherapy. For example, the electrical signals generated by fish are of a relatively low frequency and amplitude, making them well suited for use in therapeutic applications. Additionally, the electrical signals generated by fish are highly stable, making them reliable and predictable. The use of fish bioelectricity in electrotherapy has several potential applications in the treatment of various medical conditions. For example, electrical stimulation can be used to reduce pain and inflammation, to improve circulation and promote tissue healing, and to promote relaxation and reduce stress. Electrical stimulation has also been used to improve the function of the nervous system and to treat conditions such as paralysis and muscular dystrophy. Fish bioelectricity has great potential for use in the development of new therapeutic techniques in medicine **(Hayes &Melrose ., 2020)**. The electrical signals generated by fish are of a low frequency and amplitude, making them well suited for use in therapeutic applications. Additionally, the electrical signals generated by fish are highly stable, making them reliable and predictable. The use of fish bioelectricity in electrotherapy has several potential applications, including the treatment of pain and inflammation, the improvement of circulation and tissue healing, and the treatment of nervous system disorders. Also AI and Machine learning provided strength to the concepts like CADD, and Immunoinformatics**(Joshi et al., 2022a; Joshi et al., 2022b; Kaushik et al., 2022; Joshi et al., 2021; Sarkar et al., 2023; Joshi et al., 2022c; Joshi & Kaushik., 2021; Mishra & Dewangan., 2013; Khunte & Mishra., 2022)**, similarly the continued study of fish bioelectricity and its applications in electrotherapy holds great promise for the development of new and innovative therapeutic techniques in medicine.

Conclusion

In conclusion, the study of fish biomechanics and bioelectricity provides valuable insights into the unique physiological and behavioral adaptations that allow these animals to survive and thrive in their aquatic environments. Through the use of mathematical models and cutting-edge experimental techniques, researchers have been able to gain a deeper understanding of the mechanisms underlying fish movement and the production of electric fields. The bioelectricity generated by fish plays a critical role in many aspects of their biology, including predator avoidance, prey detection, and communication. Similarly, the complex musculo-skeletal systems of fish enable them to generate powerful, precise movements that allow them to swim and maneuver with remarkable efficiency. The study of fish biomechanics and bioelectricity has important implications not only for our understanding of these remarkable animals but also for the development of new technologies and applications. For example, the study of fish electrogenesis has led to the development of new electrotherapy techniques for the treatment of a variety of medical conditions, and the study of fish biomechanics has inspired the development of new underwater propulsion systems for military and industrial applications. Overall, the study of fish biomechanics and bioelectricity continues to provide valuable insights into the unique and fascinating adaptations of these animals, and holds great promise for the future of biomedical and technological innovations.

Conflict of Interest

Not Applicable

Author Contribution

AJ and PS wrote the MS and AJ verified the MS.

Acknowledgement

All author's like to acknowledge Kalinga University Raipur Chhattisgarh, India for support and Assistance.

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