The Spark Within

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SUMMARY

Bioelectricity is an emerging field of study among biophysicists that refers to the electrical component of biological processes. All healthy cells are polarized and form complex networks of electrical patterns that are essential for cell communication and signaling within the body. Proper cell polarization patterns are also necessary for normal tissue growth and organ regeneration.

One of the most famous projects concerning the influence of bioelectricity was conducted at Tufts University in 2016 by Michael Levin's team, who examined the influence of bioelectricity on organ regeneration in planaria. Here, the trunk segments of the planaria were severed and the wounds were subsequently immersed in a chemical solution that depolarized the damaged tissue. In most trials, Levin's team found that the planaria would regrow the incorrect organ; for example, the segment of the planaria with the pre-existing head would grow another head where it was wounded. Moreover, when this experiment was performed again on these newly-formed planaria, without changing the bioelectric state of the wound, the planaria would regrow the incorrect organ again. Thus, Levin's team concluded that altering the bioelectric state of a planaria's wound can alter its morphology.

Since these findings were published, many biophysicists have taken on research exploring the relationship(s) between electric, chemical, and genetic information; this will aid in understanding the mechanism in which the incorrect organ regrew in Levin's experiment. The results of these future studies will have significant impacts on the biomedical engineering and regenerative medicine fields, as well as allow us to understand more about the human body.

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Have you ever imagined what life would be like if we could design our own organisms? Nowadays, that dream is not so far away since scientists have been working diligently to discover different ways to manipulate DNA in order to achieve a desired genotypic or phenotypic outcome. Recently, biophysicists have found a lead in this field as they have come to realize the importance of bioelectric signals and cell polarization within the body (Grimnes and Martinsen, 2019).

Bioelectricity is an essential property for all living organisms. Internal communication would be impossible without the use of complex networks of electric signals. Generally, these signals can be classified as rapid-fire signals that tell you to "take your hand off the stove", or complex biological signals that tell your body to heal itself when injured (Brownell, 2020). Furthermore, the bioelectric potential of a cell is not solely the result of electric signals being transmitted, but an essential property, as cells either mutate or die when their potential collapses (Grimnes and Martinsen, 2019). This is also true for cell polarization patterns within body tissue, as the correct charge is required for tissue growth, wound healing, and organ regeneration (Davies, 2020). After discovering this in the 1990s, scientists have been fascinated with discovering the impact that altering an organism's electrical patterns has on their morphology.

In 2016, Michael Levin's team at Tufts University began to study the regeneration of planaria flatworm tissue when cut and what happens when the wound is artificially polarized (Davies, 2020) (Figure 1). To date, this is Levin's most famous experiment, as it shows a vital link between an organism's genetic and electrical framework.

Typically, when planaria flatworms are cut in half, they regenerate missing organs within 10 days after the injury (Davies, 2020), so two seemingly identical flatworms would be created. However, in Levin's experiment, for the three hours proceeding the cut of the flatworm, the bioelectric state of the wound was

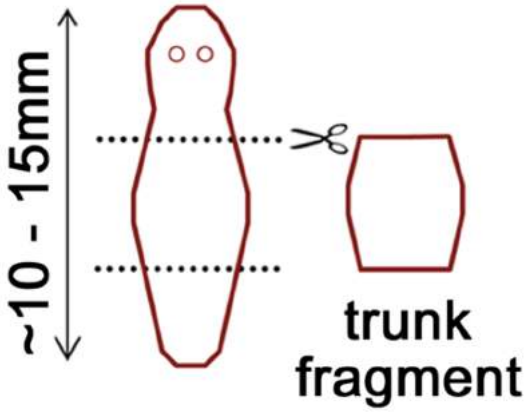

Figure 1: This figure illustrates how each Planaria flatworm was cut for Levin's experiment. The trunk segment of the Planaria was removed and the wound on both halves of the flatworm was monitored for growth (Nogi et al., 2009).

chemically altered by an ionophore solution which depolarizes tissue (Durant et al., 2019). The solution was then washed out of the wound, allowing the bioelectric state to return to normal. Nonetheless, at the six-hour mark after being cut, the worms began to exhibit signs that they were growing the incorrect organ (Davies, 2020). The half of the worm with the head began to grow another head where it was cut (Figure 2), and the same phenomenon occurred for the tail. Additionally, when these mutated worms were cut in half again- without altering the bioelectric state of the wound- they would repeatedly produce the improper organ. This led Levin's team to conclude that altering the bioelectric state of the planaria flatworm tissue immediately after being cut can permanently impact its anatomical patterning (Pietak and Levin, 2017).

Despite the fact that the planaria's morphology was drastically altered, its DNA was left unchanged (Davies, 2020). This opens greater possibly for research in the field of epigenetics, which focuses on phenotype-determining factors, as there is currently a large gap of knowledge concerning epigenetic information storage, processing, and propagation (Davies, 2020). In order to fully understand Levin's experiment, the relationship between electric, chemical, and genetic information must first be understood, in addition to the influence of epigenetic factors.

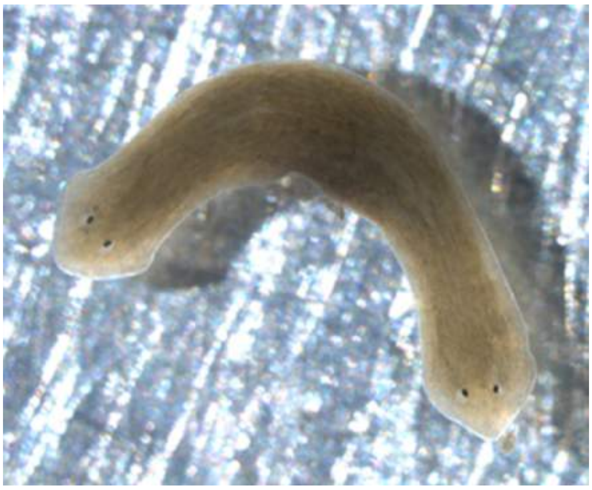

Figure 2: This figure illustrates one of the end results of Levin's experiment, where a Planaria flatworm grew heads on both ends of its body (Davies, 2020).

Since 2016, researchers have made significant progress in determining the mechanisms behind this experiment. Namely, more information was gathered about a planaria's bioelectric patterns, organ regeneration at a cellular/molecular level, and how various magnetic fields affect regeneration (Pietak and Levin, 2017). Furthermore, Michael Levin is currently leading a project that aims to understand the morphogenetic code, and specifically how bioelectric patterns are produced, how they organize cells, and how they are interpreted by a cell's genetic machinery (Brownell, 2020). Additionally, over the past decade, the relevance of bioelectricity has increased its impact in various fields, such as cancer research. Here, scientists have discovered that all healthy cells maintain a potential difference across their cell membranes, typically of a few hundred mini-volts, whereas all cancer cells are depolarized (Davies, 2020). Bioelectricity also has relevance in immunology research, as the administration of drugs which also have the ability to increase cell polarity, by causing the cell's interior to become more negatively charged, has shown to strengthen immune response (Brownell, 2020). However, this is still just the beginning of comprehending the complexity of bioelectricity.

While studying the bioelectricity of planaria is important, it is only the first step in translating bioelectricity studies into applications for humans. Ultimately all research will be useful, but since human systems differ in complexity and structure compared to planarian systems, they must be studied much further using the results of the planaria-based studies. Fully understanding the significance of bioelectric signaling in humans will be revolutionary, and the impact to both the biomedical engineering and regenerative medicine fields will be immense. For instance, the influence of electric polarization on organ growth could be applied to rehabilitation studies for amputees. Overall, the study of bioelectricity has only just begun and with talented biophysicists leading the search head-on, we can expect to see amazing discoveries in the near future.

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