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REVIEW ARTICLE

Biophysics and Surface Chemistry in Physiology

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ABSTRACT

Even though the physiology deals with the study of normal functions of the body the various physiological processes can be explained better with the help of underlying physical and chemical changes. The scientific progresses and advances in the subjects like physics, chemistry and biology gave us opportunity to apply principles of these sciences to understand the working of living organisms better. The underlying physical properties of lipids, water and their surface interaction led to the discovery of cell membrane.

The use of vegetable oil to calm the sea waves was known to mankind since 4000 BC since the time from Akkadian ruler Hammurabi, but the more scientific experiments in this area were done by Benjamin Franklin, Lord Rayleigh, Agnes Pockels and Irving Langmuir.

In this review we trace back the history of surface chemistry of lipids on water surface and their application in physiology.

Keywords: Lipid bilayers, Oil, Sea waves, Surface chemistry, Surface tension, Water.

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INTRODUCTION

Babylonian Lecanomancy

Mesopotamia is considered as the cradle of civilization. Mesopotamia in Greek means 'land between the rivers.' This is the land between the rivers 'Tigris' and 'Euphrates' located in the modern country of Iraq and Kuwait. The Sumerians were the first people to migrate to Mesopotamia.

Mesopotamia is the first region where people formed villages and farms. It is called the birth of civilization. The sumer people built temples to worship their gods and they built large cities. They used pictures for words and to write sentences. The stories on clay tablets date back to the earlier Sumerian civilization 4000 BC. They invented the oldest known written language. They wrote in clay with a suitable stylus and it was baked and the inscriptions were preserved. The Akkadians (2000 BC) dominated Sumerians and they adopted the Sumerian cuneiform to suit their own needs. The Akkadians established the Akkadian Empire. The ancient cuneiform clay tablet belonging to the Akkadian ruler Hammurabi's time (1758 BC) was discovered by David Tabor in Ashmolean Museum at Oxford. Tabor got it translated and wrote a paper on Babylonian Lecanomancy. It was probably the first scientific paper about the Sumerian manuscript dealing about the spreading of oil on the water. In Babylonian Lecanomancy a diviner made his prophecies based on the way oil spreads on water.[1,2]

The Greeks' use of Oil to Smoothen the Sea Waves

Around 1000 years after the Hammurabi's period, Greeks started using oil to smoothen the sea waves. Plutarch attributed to Aristotle (385 BC–322 BC) that 'the oil produces calm by smoothing the water surface so that the wind can slip over it without making an impression'.[3]

Gaius Plinius Secundus better known as 'Pliny the Elder' (23-79AD)–A Roman philosopher and encyclopedist had first mentioned in his encyclopedic work 'Naturalis Historia' his observations about how oil smoothened rough sea waves. He also stated that divers added oil to water to make it smoother and easier to see the bottom.[4,5]

Benjamin Franklin's Scientific Experiments

Benjamin Franklin (1706–1790)—Founding father of the United States of America, statesman, philosopher, diplomat, inventor, and self trained scientist, was the first to perform more scientific research on spreading of oil on the water. Benjamin Franklin was born in Boston on January 17, 1706. In 1757, he was sent by the American House of Assembly of Philadelphia to Great Britain. During this journey, in the fleet of 96 ships which were encountered by windy weather he noticed that two of the ships were sailing much more smoothly than the rest. After the inquiry with the Captain for a reason, he came to know that the cooks were emptying their greasy vessels, which has greased the sides of those ships.

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Almost after a decade he decided to revisit his questions on the water-calming effect of oil. In 1774, While staying in the Clapham Common area in south London he and his merchant friend Christopher Baldwin went to Lake Mount Pond, and did the experiment. One day when the pond was very rough with the wind, he dropped a spoonful of oil (probably olive oil) on the water. He saw it spread itself upon the surface, produced an instant calm over a space several yards square, which spread amazingly, and extended itself gradually till it reached the lee side, making all that quarter of the pond, perhaps half an acre, as smooth as a looking-glass and as much thinner as to be invisible, except in its effect of smoothing the waves at a much greater distance.[6,7] The oil film was thin and it produced the prismatic colors, for a considerable space, and beyond that so much thinner as to be invisible, Franklin also observed that when a drop of oil is put on a polished marble table, or on a looking-glass that lies horizontally, the drop remained in its place, and spreading of oil was very little.[6,7] In Franklin's contribution to surface chemistry, he assumed that the oil forms a monomolecular layer. Although Franklin's experiments were published, they were not noticed over a century.

Surface Tension and Spreading of Oil on Water

John Aitken—A Scottish meteorologist suggested that the calming effect of oil on water was not because of the reduction in the frictional force of the air on the surface but the surface tension on the water surface. Around 200 years after Franklin's experiments, Professor Charles Giles professor of chemistry at the University of Strathclyde identified the pond where Franklin did his experiments which still exists as 'Clapham Common'. He repeated Franklin's experiments and took photographs.[8-10]

Franklin's experiment was repeated by Lord Rayleigh. Lord Rayleigh, originally known as John William Strutt was born on November 12, 1842 at Langford Grove, Maldon, Essex. He was a grandson of Captain Richard Vicars, RE who was an outstanding scientist. He studied in Trinity College, Cambridge. In 1879, he was appointed as Professor of Experimental Physics and Head of the Cavendish Laboratory at Cambridge. In 1884, he left Cambridge to continue his experimental work at his country seat at Terling, Essex, and from 1887 to 1905 he was Professor of Natural Philosophy in the Royal Institution of Great Britain, being successor of Tyndall.

Lord Rayleigh's work ranged over almost the whole field of physics, covering sound, wave theory, color vision, electrodynamics, electromagnetism, light scattering, flow of liquids, hydrodynamics, and density of gases, viscosity, capillarity, elasticity and photography. He was awarded Nobel Prize in Physics 1904.

In 1890 Lord Raleigh conducted a series of quantitative experiments with oil and water. He was able to carefully measure the area to which a known volume of oil would expand over water and also calculated the thickness of the oil film. Foundation of modern surface chemistry was laid in 1890 by Lord Raleigh.[5,11,12]

A German woman named Agnes Luise Wilhelmine Pockels, was a German scientist. Agnes Pockels, was born in Venice, Italy, in 1862. She was a German pioneer in chemistry. Her work was fundamental in establishing surface science. She did not attend college. While taking care of her parents, she occupied her mind by reading material provided by her brother, a student at the University of Heidelburg. She conducted experiments in the kitchen sink, using kitchen bowls, string and buttons, and had developed on her own a device for carefully measuring the exact area of an oil film. Lord Raleigh assisted Agnes Pockels in publishing her work on surface tension and the results were published in the journal Nature in 1891. Her greatest contribution to science was the device that she invented, which is still used today by chemists and physicists studying surface phenomena. She invented a tin trough with a sliding barrier that was used to measure surface tension.[5,13,14]

The next important discovery was made by Sir William Bate Hardy (1864–1934) in 1912, when he found that oils without polar functional groups (Nonpolar oils-mineral oils, petrolatum,) did not spread on a water surface like oils with a polar group (polar oils- Olive oil, coconut oil, Avocado oil) and stated for the first time that polar molecules might have an orientation on the water surface, induced by long range cohesive forces between these molecules.[15]

Pinnacle of Surface Chemistry

Irving Langmuir (1881–1957) was born in Brooklyn, New York, on January 31, 1881. He graduated as a metallurgical engineer from Columbia University in 1903, and Postgraduate in Physical Chemistry under Nernst in Göttingen Germany in 1906. He was awarded Nobel Prize in Chemistry 1932.[16] Charles Tanford, a well known surface scientist states that 'scientifically Irving Langmuir represents the pinnacle of surface chemistry'.[17] Langmuir conducted research on the nature of oil films while working in the laboratories of General Electric USA. He was able to make careful measurements of surface areas occupied by known quantities of oil by using an improved version of the apparatus originally developed by Agnes Pockels known as a Langmuir trough. Langmuir in his paper on molecular monolayer proposed that the fatty acid molecules form a monolayer by orienting themselves vertically with the hydrocarbon chains away from the water and the carboxyl groups in contact with the surface of the water.[18]

This was the key piece in understanding lipid bilayers and cell membranes.

Lipid Bilayers and Cell Membranes

Gorter and Grendel extracted the lipids from red blood cells. Using a modified trough, similar to Langmuir, they were able to demonstrate that lipid molecules could form a double layer or as a monolayer. They showed that the surface area of the lipids extracted from the red blood cells was about twice the surface area of the cells themselves.[19,20]

The first membrane model was proposed by Danielli and Davson in 1935. It was basically a 'sandwich' of lipids (arranged in a bilayers covered on both sides with proteins).[21] Later they included 'active patches' and protein lined pores.[22]

The unit membrane model was eventually replaced in the early 1970s by the current model of the membrane, known as the fluid mosaic model, was proposed by biochemists Singer and Nicolson.[23] This model retains the basic lipid bilayer structure proposed by Gorter and Grendel and modified by Danielli and Davson and Robertson. The entire membrane is fluid—the lipid molecules move within the layers of the bilayer while the proteins also freely move within the bilayer.

Fat Receptors in Oral Cavity and Gastrointestinal Tract

There are fat and water receptors present in the oral cavity and the gastrointestinal (GI) tract mainly in the small intestine.[24,25] There is evidence showing that free fatty acids are important stimuli used by taste receptors for the detection of fat. The proteins for the release and transport of lipophilic fatty acids are found in the oral cavity and also the taste cells have fatty-acid-sensitive ion channels and transport molecules for the uptake of fatty acids.[26] This membrane-bound long-chain fatty-acid transporter is specifically localized to the apical parts of taste-bud cells, in the circumvallate papillae identified as CD36.

CD36 works as a dietary fat sensor and signal is sent to the brain via the glossopharyngeal nerve.[27] CD36 is also present on apical enterocyte membranes of small intestine and it is a major mediator of fatty acid-induced release of CCK and secretin.[28] GPR40 and GPR120 are potential drug target for type 2 diabetes.[29-31]

The mean total surface area of the oral cavity is 215 cm^2. When saliva is spread evenly throughout as a thin film it forms 70 to 100 µm thick layer. The average unstimulated salivary flow rate is 0.3 to 0.4 ml per minute. During sleep, the salivary flow rate is negligible and its protective effect is lost.[32]

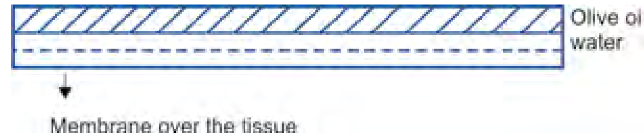

Fig. 1: Olive oil layer over water

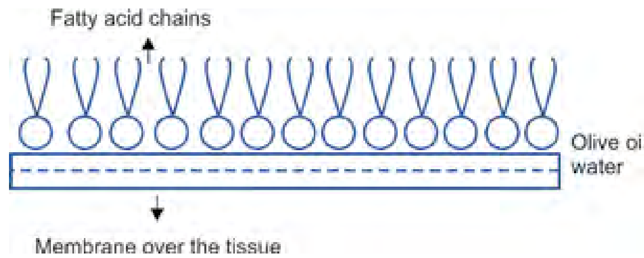

Fig. 2: Monolayer of olive oil

The olive oil significantly decreases bacterial growth and adhesion in the oral cavity.[33] Virgin olive oil decreases water evaporation.[34] Lipids add hydrophobic characteristics to the tooth surface thus hampering bacterial colonization and decreasing caries susceptibility. Also lipid-enriched pellicles are more resistant in case of acid exposure and therefore reduce the erosive mineral loss.[35] Swishing of 1 to 2 ml of olive oil is sufficient to form a thin film in the entire oral cavity thus helping to prevent bacterial adhesion and growth. Virgin olive oil forms a film over tissues in the oral cavity and this protects the tissues in the oral cavity at night when salivary secretion is reduced as it also decreases evaporation of water in the oral cavity. Virgin olive oil can be used as oral hygiene supplement in the oral cavity (Figs 1 and 2).[35]

Apart from CD36 many G-protein-coupled receptors-GPR 40, 41, 43, 84, 119 and 120 for free fatty acids in stomach, intestine, pancreas, adipocytes which are involved in modulation of many hormonal secretion like ghrelin, secretin, insulin and glucagon. Extravirgin olive oil improves postprandial glucose and LDL-Cholesterol, and this effect may account for the anti atherosclerotic effect of the mediterranean diet.[36]

CONCLUSION

Virgin olive oil can be used as oral hygiene supplement to prevent dental and periodontal infections and it has a role in reduction of cardiovascular diseases and blood glucose rise after meal.[35] As large number of people in developing countries are suffering from dental and periodontal infections a nutrient like vegetable oil (sesame oil, sunflower oil, coconut oil and olive oil) in small quantity (2 to 3 ml) can be used as oral hygiene supplement.

We are dedicating this article to the teachers and our former presidents Dr S Radhakrishnan and Dr APJ Abdul Kalam.

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