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SQUALENE EXPLORING ITS VITAL ROLES IN VACCINE PRODUCTION, SKIN CARE, CHOLESTEROL METABOLISM, ANTI-CANCER STRATEGIES, CARDIOVASCULAR HEALTH, AND ANTIOXIDANT POTENCY

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Squalene (SQ) is a naturally occurring hydrocarbon compound found abundantly in various sources, including shark liver, olive, and plant oils. SQ plays a pivotal role as a precursor molecule in humans and animals in synthesizing vitamins, cholesterol, and steroid hormones, maintaining healthy skin, and protecting against UV radiation-induced carcinogenesis. In the realm of medicine, SQ has emerged as a promising adjuvant in vaccines. Its role in enhancing immune responses has been studied extensively, contributing to the efficacy of influenza and COVID-19 vaccines. SQ has been confirmed to possess strong anti-tumor activity and inhibitory features against the development of cancer. Because of this, it is frequently used as a supplementary treatment for many forms of cancer. Intriguing and hopeful are the epidemiologic and laboratory studies looking into SQ's anti-cancer properties. Furthermore, SQ's stability during storage and technological processes adds to its appeal as a dietary supplement and functional ingredient in various food products. Additionally, as research progresses, the understanding of SQ's safety and efficacy continues to expand, providing a solid foundation for exploring its potential in various applications. This article study focuses on exploring the multifaceted uses of SQ in medicine, cosmetics, and nutrition.

Keywords: *Antioxidant, Squalene, Vaccine, Skin disorder, Anti-cancer*

INTRODUCTION

The inception of SQ traces its roots to 1906, when Mitsumaru Tsujimoto, a distinguished Japanese industrial engineer, made the initial identification. Subsequently, in the 1950s, the presence of SQ in the human body was discovered, coinciding with the recognition of its association with cholesterol metabolism. This compound assumes a noteworthy role as an intermediary in cholesterol metabolism. Furthermore, contemporary research has unveiled its prevalence in diverse bodily regions, including the skin, membranous linings of the gastrointestinal and respiratory tracts, as well as fat tissue.[1] In 1963, new research possibilities emerged when a study published in the scientific journal Nature revealed that SQ can activate macrophages, which are the principal immune cells responsible for safeguarding our bodies' inner and outer protective layers .[2] Subsequently, in 1995, a research group from Japan presented compelling evidence demonstrating the efficacy of SQ in safeguarding the skin against lipid oxidation induced by Ultraviolet (UV) radiation. This groundbreaking discovery significantly elevated SQ's status in the scientific community. In 1996, a human study was conducted to assess the potential of SQ in reducing blood cholesterol levels. SQ, categorized as an isoprenoid hydrocarbon composed of six isoprene units, is naturally present in our bodies and from various natural sources.[3] Isoprenoids, including SQ and lycopene, are a class of compounds known for their exceptional antioxidant properties.

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Notably, many antioxidants, such as vitamin E, vitamin A, beta-carotene, and flavonoids, either belong to the isoprenoid family or possess an isoprenoid tail. Among the diverse array of isoprenoids found in nature, biologists are particularly intrigued by the select few, like SQ and lycopene, which exhibit extraordinary antioxidant capabilities.[4] SQ boasts an effective and stable antioxidant configuration due to its pure isoprenoid composition, comprising solely isoprene units. When purified, SQ takes the form of a colorless, nearly tasteless, transparent liquid with minimal odor. It serves as the major hydrocarbon component in fish oils. It is essential to emphasize that SQ is derived from fish oil and falls under the category of polyunsaturated lipids, to avoid conflict with a vital fatty acid).[5] The review aims to explore the biological roles and functions of SQ in the human body and other organisms study the potential health benefits associated with SQ, such as its antioxidant and anti-inflammatory properties, and assess the safety and tolerability of SQ in various applications, such as skin care, pharmaceuticals, and food products.

Animal and Plant Sources of Squalene

The liver of deep-sea sharks represents the most ideal and abundant source of SQ, with the dogfish shark being notably distinguished as the producer of the highest-grade SQ. These sharks, known for their deep-dwelling habits, inhabit ocean depths that exceed 3000 meters (m).[6] The sharks' capacity to withstand the harsh conditions of their habitat is ascribed to their exceptionally large liver, constituting approximately 70% of their internal organs. Within this oversized liver, SQ is present in significant quantities, ranging from 50% to 70%. SQ plays a crucial role as a key energy source for sharks, allowing them to flourish in the inhospitable and oxygen-depleted environment of deep-sea depths.[7]

Sources of SQ derived from vegetables include olive oil and amaranth. Historically, ancient Mediterranean cultures attributed increased strength and longevity to olive oil, which is a significant source of SQ. However, extra-virgin olive oil contains a relatively modest amount of SQ, approximately 200 - 450 mg per 100 g of oil.[8] SQ can also be found in various fungi. One of the significant sources of SQ in fungi is the yeast species Saccharomyces cerevisiae. Studies have shown that this yeast species can produce and accumulate substantial amounts of SQ, making it a valuable source of this compound.[9] SQ is also found in certain bacteria, particularly in members of the order Planctomycetales. One of the well-known bacteria capable of producing SQ is the species Rhodopseudomonas palustris. This bacterium has been identified as a significant source of SQ in the microbial world.[10]

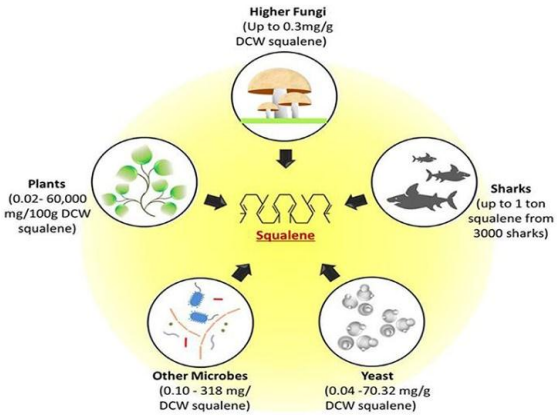

Fig.1: Reveals the Sources of squalene distribution in the environment (11)**.**

Squalene's Biochemical Aspects

Squalene is a 30-carbon polyprenyl compound consisting of 6 isoprenoid units **(Fig. 2).** It shares structural similarities with beta-carotene and serves as an intermediary in the synthesis of cholesterol. Additionally, SQ and related compounds, such as oxidosqualene and bis oxidosqualene, act as precursors for about 200 triterpenes.[12]

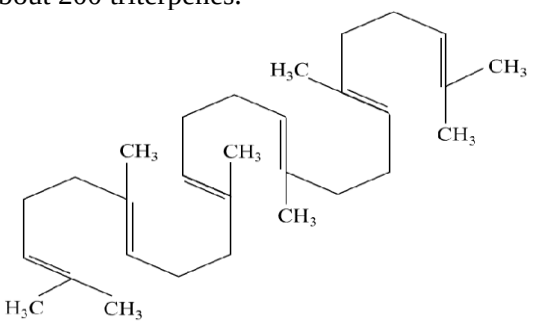

Fig. 2: Reveals the chemical structures of SQ (13).

The process of generating SQ in nature commences with the creation of 3-hydroxy-3-methyl glutaryl coenzyme A (HMG-CoA), as illustrated in **Fig.** 3 and elucidated by reference[12]. HMG-CoA is produced from acetyl CoA, followed by the conversion of HMG-CoA into mevalonate through a reaction dependent

on niacin. Subsequently, mevalonate goes through three phosphorylation stages with the assistance of a magnesium-dependent catalase enzyme [14]. These steps involve the formation of 5-phosphomevalonic acid, 5-pyrophosphomevalonic acid, and isopentenyl pyrophosphate.[14] Eventually, the compound is decarboxylated, forming 3 isopentenyl diphosphates, which act as the donor for various prenyl compounds. SQ is synthesized when two molecules of farnesyl diphosphate combine through an enzymatic process and undergo niacin-dependent reduction.[9] After the biosynthesis process, SQ is converted into cholesterol and various other steroid metabolites.[15]

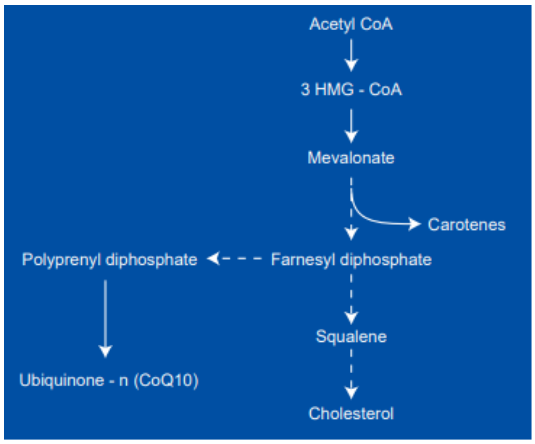

Fig. 3: Reveals the Synthesis of SQ, Carotene, Cholesterol, and Coenzyme Q10 (17).

Squalene is a Potent Natural Antioxidant

Earlier research has demonstrated that SQ possesses remarkable effectiveness in scavenging singlet oxygen.[15] Consequently, due to its antioxidant properties, SQ was deemed to be capable of countering oxidative stress and the rise of ROS, which can trigger cancer.[17] This, in turn, led to the recognition of SQ as a promising anti-cancer agent.[13] Despite being recognized as an antioxidant, the scavenging capacity of SQ has not undergone extensive investigation and has recently faced challenges from new studies. [18] found no evidence of antioxidant activity in SQ against stable radicals like 2,2-diphenyl-1-picrylhydrazil, cation radicals such as 2,20-casino-bis (3-ethylbenzthiazoline-6-sulphonic acid), or peroxyl radicals induced by 2,20-azobis(2-methylpropinamid) dihydrochloride, even at high concentrations. Similar findings have been previously reported.[19-20] Based on the available evidence, SQ's antioxidant activity appears to be remarkably low. Nevertheless,[21] provided an alternative perspective, reporting an antioxidant effect with an IC50 value of 0.023 mg/mL for SQ. In a crocin bleaching assay, SQ demonstrated the ability to decrease the oxidation rate, possibly competing with tocopherol and sitosterol.[22] While a relatively weak antioxidant activity of SQ was also observed in olive oil[19], it is worth considering that this might be attributed to the competitive oxidation of various other lipids present in such samples. [23] further contribute to the ongoing understanding of SQ's antioxidant capabilities. In their study, the researchers extensively investigated the influence of SQ on the oxidative stability of Polyunsaturated fatty acid (PUFA), revealing its capacity as an antioxidant by acting as a scavenger for peroxyl radicals during the mild UVA-mediated oxidation of PUFA. When used in conjunction with PUFA, SQ brought about a decline in lipid peroxidation within the cardiac tissue of rats.[24] Intriguingly, the antioxidative impacts of SQ displayed variations among diverse cell types. While SQ displayed antioxidant characteristics in vitro within mammary epithelial and bone marrow cells, it did not manifest the same response in human breast cancer and neuroblastoma cells,[18] despite reference antioxidants showing efficiency in all cell types.[18], proposed that the selectivity of SQ's antioxidant activity may depend on three factors: (i) the "glutathione paradox," wherein SQ increases glutathione levels in normal cells [25];(ii) differences in SQ uptake, utilization, and accumulation [26]; or (iii) disruptions in antioxidant systems in tumor cells.[27] As a result, SQ's action may lean more toward cancer prevention rather than direct treatment

Clinical Application of Squalene

Squalene and Cholesterol Metabolism:

Regularly administering oral squalene seems to reliably reduce the levels of plant sterols in the liver and bloodstream.[28] However, its precise influence on human cholesterol metabolism is not firmly established. Existing data indicates that a significant portion of dietary Squalene is taken in by the body and transformed into cholesterol. Nonetheless, this rise in cholesterol production does not

consistently result in elevated levels of cholesterol in the bloodstream. This might be due to a simultaneous increase in the removal of cholesterol through feces.[29]

In a research project where individuals were given a daily dietary addition of one gram of SQ for nine weeks, significant rises were observed in serum cholesterol levels, as well as in very low-density lipoprotein (VLDL), intermediate-density lipoprotein (IDL), low-density lipoprotein (LDL), with increases of 12%, 34%, 28%, and 12% respectively. However, when the same participants were subsequently shifted to a lower dosage of SQ (0.5 g/day) for six weeks, their levels of serum sterols returned to their normal state, as documented by [29].

In another investigation by [29], human subjects were supplemented with SQ at a daily dose of 900 mg for 7-30 days. This resulted in a significant 17-fold increase in serum SQ levels, but no significant changes were observed in serum triglyceride and cholesterol contents. Notably, SQ feeding did lead to a substantial rise in fecal excretion of cholesterol, its nonpolar derivatives, and bile.[30]

Substituting dietary triglycerides with SQ is documented to lead to a cholesterol absorption decrease of around 50% in rats.[31] Nevertheless, human studies' findings indicate no alteration in cholesterol absorption when incorporating SQ into the diet. This implies that the reduction in cholesterol absorption was likely due to the removal of triglycerides rather than the introduction of SQ. [29- 30]

Squalene and Vaccines

Vaccines stand as a remarkable accomplishment in contemporary scientific advancements, protecting countless lives from infectious diseases. They comprise components of the pathogen such as fragments of proteins, and in certain instances, may include inactivated or live viruses, as is the case with seasonal influenza vaccines.[32] The first vaccine adjuvant, potassium aluminum sulfate salt (Kal $(SO_4)_2 \cdot 12H_2O$; Alum), Originated in the 1920s, this formulation was the exclusive type utilized for more than seven decades. Examples include glycosylated triterpenes saponins, bacteria-derived adjuvants that enhance innate immunity by stimulating Toll-like receptors (TLRs), such as monophosphoryl lipid A (MPLA) or oligodeoxynucleotides. Furthermore, adjuvants, including SQ-based oil-in-water (o/w) are currently employed to enhance vaccine efficacy.[33]

Squalene is considered a secure and reliable choice for incorporation into pharmaceutical formulations. Three emulsions of oil-in-water -MF59 (Novartis), AS03 (GSK), and AF03 (Sanofi)-employ SQ droplets stabilized by nonionic surfactants.[32] These emulsions have been authorized for vaccinations against the seasonal and pandemic flu. Studies conducted on mice have demonstrated that adjuvants based on SQ function as carriers for antigens, effectively boosting both innate and adaptive immune responses.[34]

Novartis Squalene (MF59) Adjuvant Vaccines

Novartis (MF59), which consists of SQ, polysorbate 80, and sorbitan tioleate, acts as both an approach for transferring antigens and an immunomodulator.[35-36] Although there is no evidence of a depot effect, MF59's muscular injection results in a localized increase in chemokines and cytokines, leading to the rapid recruitment of immune cells.[35] Despite enhancing innate immunity, Novartis-triggered antibody replies are independent of Toll-like receptors (TLRs) and inflammasomes, instead relying on myeloid differentiation primary response 88 (MyD88) for activation. MF59 stimulates innate immune responses, activating antiviral gamma interferon (IFN-γ) signaling-related genes, thereby activating monocyte and dendritic cell responses.[37]

GlaxoSmithKline (AS03) Squalene Adjuvant Vaccines

The AS03 adjuvant possesses a composition akin to MF59, yet it incorporates α-tocopherol, which amplifies cytokine release and favorably influences innate immune responses. As well as being used in numerous recombinant protein spike COVID-19 vaccines, AS03 is also used in pandemic influenza vaccinations.[38] Although the precise molecular processes underlying AS03-induced immunity have not been fully elucidated, due mainly to α-tocopherol, it is known to have a dose-sparing effect.[39] Locally, α-tocopherol promotes the synthesis of chemo-attractants for monocytes

(CCL2) and neutrophils (CCL3).[40] By activating the endoplasmic reticulum (ER) stress-related pathway, AS03 increases the expression of IL-6 and granulocyte colony-stimulating factor (G-CSF) in mice.[41] Increased cell recruitment and antibody titers result from this in draining lymph nodes (dLNs).[42]

Sanofi (AF03) Squalene Adjuvant Vaccines

The Sanofi Pasteur-developed AF03 adjuvant is an oil-in-water emulsion comprising SQ.[43] Despite being a component of the influenza vaccine against the H1N1 virus. Due to the small number of studies that have been done on vaccines that contain AF03, the precise molecular processes behind the immunological activation caused by AF03 are still mostly unclear. Nonetheless, existing reports suggest that AF03 enhances IL-5 and IFN-γ immune responses in mice and elicits an increase in influenza virus-neutralizing antibodies in animals administered with different AF03-adjuvanted vaccines.[44] Recent findings have also indicated that anti-SARS-CoV-2 vaccines adjuvanted with either AS03 or AF03 induce higher antibody titers compared to non-adjuvanted vaccines.[45] Currently, the array of vaccine adjuvants has expanded to include diverse delivery vehicles, immunomodulators, and even small molecules targeting key mediators of the immune response, such as TLR agonists.[38] The emergence of the COVID-19 pandemic has highlighted an inconvenient truth: traditional sources such as shark liver oil and plant oils are inadequate to sustainably fulfill the global vaccine demand. Consequently, the need to distribute COVID-19 vaccines on a global scale is projected to considerably amplify the necessity for SQ, potentially posing threats to ecosystems and leading to an escalation in its price.[46]

Squalene and Skin Disorders

SQ is abundant in the skin and functions as a defense against free radicals. When it encounters free radicals, SQ chemically reacts with them through a quenching process, forming a new molecule called SQ hydroperoxide. While SQ hydroperoxide is not an antioxidant, it serves as an excellent emollient in the skin, acting as a natural sunscreen and moisturizer.[37] SQ offers relief, protection, nourishment, and restoration for dry and sensitive skin. When applied topically, SQ can aid in wound healing, scar prevention, and effective moisturization. It helps maintain skin smoothness and suppleness, preventing the development of fine lines and wrinkles. Squalane, a synthesized form of SQ, is utilized in cosmetics due to its enhanced stability compared to SQ. Unlike internal mucosae, the skin is directly exposed to sunlight, including UV-B radiation, which generates free radicals and poses a risk of skin damage. Multiple research studies support SQ's role in safeguarding the skin from UV radiation.[47-48] This could explain why sebum, the skin's natural oil, contains a high proportion (12%) of SQ in the skin.[49]

SQ has emerged as a promising therapeutic agent for addressing skin disorders and promoting wound healing, with several studies supporting its beneficial effects in these applications. Concerning skin disorders, SQ's antioxidant properties are particularly beneficial in shielding the skin from oxidative stress and mitigating damage caused by free radicals.[50] Additionally, SQ's moisturizing and emollient characteristics contribute to improving skin hydration and reducing dryness, making it a valuable component in various skincare products.[51]

In the context of wound healing, research has shown that SQ may play a significant role in accelerating the healing process. Its anti-inflammatory properties have been observed to help in reducing inflammation at the wound site, creating an environment conducive to tissue repair and regeneration.[52] Moreover, SQ's ability to enhance collagen production may contribute to wound closure and the formation of new tissue.[53]

Research has indicated that administering SQ at high doses (exceeding 13.5 g daily) in vivo resulted in reduced wrinkles on aging human skin, increased levels of type I procollagen, and a decrease in DNA damage caused by UV exposure.[54] Additionally, there are scientific papers exploring the protective effects of SQ against skin cancers. SQ is recognized as one of nature's most essential hydrating agents. It has the remarkable ability to swiftly and effectively penetrate the skin, providing beneficial elasticity and restoring flexibility without any greasy residue. Recent

experimental investigations have focused on newly developed cosmetic emulsions containing biomimetic molecules that incorporate SQ.[55]

Squalene and Anti-Cancer Effects

Cancer poses a significant threat to humanity, characterized by the uncontrolled growth of cells that can spread to other parts of the body. Numerous studies have indicated that incorporating SQ into one's diet could potentially hinder the growth of tumor cells, particularly in breast, pancreas, colon, and melanoma cancers. These types of cancer rely on the prenylation of proteins for their activation, and SQ consumption has been linked to inhibiting this process. [56-57] SQ has been investigated for its potential anti-cancer properties, and several studies have explored its role. Research suggests that SQ exhibits anti-cancer effects due to its ability to inhibit tumor growth and proliferation. Studies have shown that SQ can induce apoptosis, in cancer cells, thereby impeding their uncontrolled growth.[58] Additionally, SQ has been found to possess anti-angiogenic properties, meaning it can hinder the formation of new blood vessels that tumors require for sustained growth.[59] Moreover, SQ's antioxidant properties play a crucial role in neutralizing free radicals, which can cause DNA damage and contribute to cancer development.[60] By reducing oxidative stress, SQ may help protect cells from potential carcinogens and mutations.

Furthermore, some studies have highlighted SQ's ability to enhance the effectiveness of certain anti-cancer treatments. For instance, in combination with chemotherapy or radiation therapy, SQ has demonstrated potential in improving treatment outcomes and reducing adverse effects. While research into SQ's anti-cancer properties is still ongoing, these findings suggest that it may hold promise as a complementary approach in cancer therapy. However, it is essential to note that more extensive clinical studies are required to fully understand its potential in anti-cancer treatment. [61]

Squalene and Cardiovascular Disease

Cardiovascular diseases remain a leading cause of morbidity and mortality worldwide. Chronic heart failure, various cardiovascular conditions, heart infarction, endothelial dysfunction, and hypertension are significant contributors to the global burden of cardiovascular diseases. In recent years, there has been growing interest in exploring natural compounds with potential cardioprotective properties, and SQ has emerged as a promising candidate in cardiovascular research.

Squalene and Chronic Heart Failure

Chronic heart failure is a complex syndrome characterized by the heart's inability to pump blood effectively, leading to reduced cardiac output and impaired exercise tolerance. Oxidative stress and inflammation play crucial roles in the pathophysiology of chronic heart failure. Studies on animal models have shown that SQ supplementation may attenuate oxidative stress, reduce inflammation, and improve cardiac function in chronic heart failure.[62] SQ's antioxidant properties have been implicated in protecting cardiomyocytes from oxidative damage, and its potential as a therapeutic agent in the management of chronic heart failure warrants further investigation.

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Squalene and Cardiovascular Conditions

Cardiovascular conditions encompass a broad spectrum of diseases, including atherosclerosis, arrhythmias, and heart valve disorders. Atherosclerosis, characterized by the build-up of fatty plaques in arterial walls, is a major underlying cause of many cardiovascular diseases. SQ's potential as an antioxidant and its role in reducing oxidative stress could be beneficial in combating atherosclerosis.[63] Moreover, SQ has been associated with improvements in lipid profiles, which may contribute to its cardiovascular benefits.[64]

Squalene and Heart Infarction (Myocardial Infarction)

Heart infarction, commonly known as myocardial infarction or heart attack, occurs when blood flow to a part of the heart is blocked, leading to the death of heart muscle cells. Ischemia-reperfusion injury, the damage caused by the restoration of blood flow following ischemia, exacerbates the severity of heart infarction. Studies on animal models have shown that SQ may reduce infarct size, attenuate ischemia-reperfusion injury, and improve post-infarction cardiac function.[65] SQ's

potential to protect against ischemic damage highlights its cardioprotective properties in heart infarction.

Squalene and Endothelial Function

Endothelial function plays a crucial role in maintaining vascular health, regulating blood flow, and preventing atherosclerosis. Endothelial dysfunction is associated with many cardiovascular diseases, including hypertension and atherosclerosis. SQ has been found to enhance endothelial function by promoting nitric oxide production and vasodilation.[66] Nitric oxide is key in maintaining vascular tone and preventing endothelial dysfunction. SQ's ability to enhance endothelial function suggests its potential to promote cardiovascular health.

Squalene and Blood Pressure Regulation

Hypertension, or high blood pressure, is a major risk factor for cardiovascular diseases. Studies have investigated SQ's potential effects on blood pressure regulation. Animal studies have shown that SQ may exert favorable effects on blood pressure levels, indicating its potential as a candidate for hypertension management.[67] SQ's potential as a vasodilator may contribute to its ability to regulate blood pressure and improve vascular health.

Squalene and Metabolic syndrome

Metabolic syndrome is a complex condition characterized by dyslipidemia, hypertension, diabetes, and obesity.[68-69] To address this condition, multiple interventions are necessary, with lifestyle changes being the primary approach, and in severe cases, drug administration may be required.

Abdominal adiposity and obesity are visible manifestations of metabolic syndrome, even before other underlying symptoms emerge. Peltola and colleagues have highlighted that elevated levels of serum SQ are associated with visceral obesity. Adipose tissue synthesizes and stores SQ, which is only partially converted to cholesterol. The researchers propose that SQ in adipose tissue might have adverse effects on abdominal obesity, making SQ a potential marker for metabolic syndrome.[70] Similarly, Lupattelli and collaborators have demonstrated that individuals with metabolic syndrome exhibit a low synthesis of cholesterol and high absorption of SQ, leading to increased plasma concentrations of SQ.[71] Despite these findings, there is limited data available to fully comprehend the crucial role of SQ in metabolic syndrome and its impact on systemic oxidative stress levels. This raises significant questions about the role of SQ in the condition and its potential implications.[72]

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استكشاف السكوالين وأدواره الحيوية في إنتاج اللقاحات، والعناية بالبشرة، وأيض الكوليسترول، واستراتيجيات المضادة للسرطان، وصحة القلب والأوعية الدموية، وقوة المضادات الأكسدية

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السكوالين (SQ) هو مركب هيدروكربوني طبيعي يوجد بشكل وفير في مصادر متنوعة، بما في ذلك كبد القرش وزيت الزيتون وزيوت النباتات. يلعب السكوالين دورًا بارزًا في تركيب الفيتامينات والكوليسترول والهرمونات الاستيرويدية في البشر والحيوانات، ويساهم في الحفاظ على البشرة الصحية وحمايتها من تكون الأورام بفعل الإشعاعات الفوق البنفسجية. في مجال الطب، ظهر السكوالين كمساعد مُشجع في اللقاحات، حيث تم دراسته بشكل مكثف لدوره في تعزيز الاستجابات المناعية، مما ساهم في فعالية لقاحات الإنفلونزا وكوفيد-١٩. تم تأكيد أن السكوالين يتمتع بنشاط قوي مضاد للأورام وخصائص مثبطة لتطور السرطان. ولهذا السبب، يُستخدم بشكل متكرر كعلاج إضافي لأنواع متعددة من السرطان. دراسات وبحوث ملهمة ومبشرة تتناول خصائص السكوالين المضاد للسرطان من خلال الدراسات الوبائية والمختبرية. بالإضافة إلى ذلك، استقرار السكوالين أثناء التخزين والعمليات التكنولوجية يزيد من جاذبيته كمكمل غذائي وعنصر وظيفي في منتجات الأغذية المتنوعة. وبالإضافة إلى ذلك، مع تقدم البحوث، يستمر فهم السكو الين وسلامته وفعاليته في التوسع، مما يوفر أساسًا قويًا لاستكشاف إمكانياته في مجموعة متنوعة من التطبيقات. تركز هذا الدراسة في هذا المقال على استكشاف الاستخدامات المتعددة للسكوالين في مجالات الطب ومستحضرات التجميل والتغذية.