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Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS): Evidence for Safe Use in Household Cleaning Products

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ABSTRACT: Environmental chemical exposure is a major concern for consumers of packaged goods. The complexity of chemical nomenclature and wide availability of scientific research provide detailed information but lends itself to misinterpretation by the lay person. For the surfactant sodium lauryl sulfate (SLS), this has resulted in a misunderstanding of the environmental health impact of the chemical and statements in the media that are not scientifically supported. This review demonstrates how scientific works can be misinterpreted and used in a manner that was not intended by the authors, while simultaneously providing insight into the true environmental health impact of SLS. SLS is an anionic surfactant commonly used in consumer household cleaning products. For decades, this chemical has been developing a negative reputation with consumers because of inaccurate interpretations of the scientific literature and confusion between SLS and chemicals with similar names. Here, we review the human and environmental toxicity profiles of SLS and demonstrate that it is safe for use in consumer household cleaning products.

KEYWORDS: surfactant, media claims, product formulation, ingredient safety review

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Introduction

Sodium lauryl sulfate (SLS), also known as sodium laurilsulfate or sodium dodecyl sulfate, is an anionic surfactant commonly used as an emulsifying cleaning agent in household cleaning products (laundry detergents, spray cleaners, and dishwasher detergents). The concentration of SLS found in consumer products varies by product and manufacturer but typically ranges from 0.01% to 50% in cosmetic products[1,2] and 1% to 30% in cleaning products.[3,4] SLS can be synthetic or naturally derived. This chemical is synthesized by reacting lauryl alcohol from a petroleum or plant source with sulfur trioxide to produce hydrogen lauryl sulfate, which is then neutralized with sodium carbonate to produce SLS.[5]

SLS (CAS# 151–21–3; MW 288.38 g/mol; pH 7.2) is a nonvolatile, water-soluble (100–150 g/L at room temperature) compound with a partition coefficient (log P_{ow}) of 1.6 – making it a relatively hydrophilic compound.[6–8] Generally, hydrophilic compounds have a low soil/sediment adsorption coefficient and low bioconcentration factors (BCFs). The BCF for SLS ranges from 2.1 to 7.1.[6,7] Down-the-drain cleaning products release SLS into the environment via household wastewater systems. In the environment, >99% of SLS readily biodegrades into nontoxic components per the OECD 301 standard.[7]

Consumers may be exposed to SLS by using products that contain the ingredient. Exposure to SLS from household cleaning products depends on the frequency of household cleaning activities, which is reported as being 1–2 times per week on average.[9] The intended application of detergents and cleaners should not result in direct contact with product ingredients; however, misuse of the product could potentially cause dermal (skin and ocular) or inhalation exposure.[9] Oral exposure to cleaning products is unlikely but has occurred – mostly in children – because of accidental ingestion.[10] With regular use of cleaning products, the delivered dose of SLS from dermal or inhalation exposure is expected to be low given the low volatility and dermal absorption rate of SLS.[6,7]

Since the early 1990s, misconstrued information on the human and environmental toxicity of SLS has led to consumer confusion and concern about the safety of SLS as an ingredient in household products.[11] As scientific literature is inherently vulnerable to misinterpretation by the general public, health and safety claims made by marketing campaigns do not always align with the latest peer-reviewed scientific evidence. Oftentimes, consumer product claims use language in ways that can be misleading to the average consumer. Review of the human and environmental toxicity profiles of SLS is warranted to elucidate the known risks and benefits of using SLS in household cleaning product formulation.

Review of SLS Toxicity Profiles

Here, we provide a review of the human and environmental toxicity profiles for SLS in order to address the most common consumer concerns about the ingredient. Unsubstantiated claims regarding the safety of SLS found in print and online media are used to exemplify the origin of several common misconceptions. Each human health and environmental claim is assessed against peer-reviewed scientific evidence for accuracy and validity. This review clearly demonstrates the known risks and benefits of using household cleaning products that contain SLS. Table 1 summarizes the available toxicology data on SLS.

Human Toxicity Profile

Acute toxicity. *Ocular irritation.* Like most chemicals, SLS can be irritating to the eye when delivered neat as a raw material or at high concentrations. At concentrations <0.1% (w/w), SLS is nonirritating to the eyes of laboratory animals.[1] For this reason, it is imperative for consumer product manufacturers to test finished products for ocular irritation. The U.S. Consumer Product Safety Commission (CPSC;16 C.F.R. §1500) requires consumer product manufacturers to perform irritation tests that appropriately characterize the ocular toxicity of the product.[12] Manufacturers are required to label the product with the appropriate warnings and first aid information according to the mandatory labeling requirements of the CPSC.[12]

SLS is cited as causing severe eye damage and blindness.[13] These claims typically point to a study published by Green et al.[14] in the journal *Lens and Eye Toxicity Research.* The study shows that after the occurrence of physical or chemical damage to the eye, corneal exposure to a high concentration of SLS can result in a slowed healing process. The findings presented by Green et al.[14] do not suggest that ocular exposure to consumer products containing SLS causes blindness or severe damage to the cornea.

In response to the media attention generated by a company promoting the anti-SLS campaign at the time – Green, the study's lead author, was interviewed regarding this work. Green stated that the company had misquoted the results and made claims that were not supported by his findings.[15] His legal counsel later issued a letter to the company stating:

> *…your citation of his work was not simply a misinterpretation, it was plainly wrong. By citing his research in support of erroneous conclusions, you have libeled Dr. Green. In fact, [you have] even attributed quotations to Dr. Green which he has never written or spoken, and which he would not ever write or speak.*[15]

In this case, the dissemination of misconstrued results not only provided a disservice to the general public but also caused serious repercussions for the scientific researchers.

A second erroneous ocular health claim made about SLS is its link to cataract formation.[16,17] Claims about SLS causing cataract formation tend to cite a 1987 study in the *Journal of Biological Chemistry.*[18] This study[18] – along with several others[19–21] – uses SLS to model cataract formation experimentally. In a controlled laboratory environment, cataract formation can be induced by immersing the lens of the eye in a concentrated solution of SLS. While concentrated SLS is useful as an experimental irritant, this is not relevant to evaluating human exposure to SLS in household cleaning products. Ocular irritation has been induced *in vivo* using SLS concentrations equivalent to a rinse-off personal care product containing 20% SLS.[17] However, this was achieved after the eyes of laboratory animals were repeatedly exposed to 0.5 mL of shampoo for 14 days.[17] While SLS is useful in studying the formation and repair of cataracts in laboratory settings, studies of this nature are not appropriate for assessing the risk of human exposure to SLS in cleaning products.

Furthermore, it should be noted that the anatomy of the eye renders direct exposure of the lens to SLS impossible, as it is deep within the eye protected by the cornea, and therefore, not vulnerable to exposure through typical consumer product usage.[22,23] As such, a causal relationship between SLS in consumer products and cataract formation is not scientifically supported.

Table 1. Toxicity of SLS (CAS# 151–21–3).

	ACUTE ORAL (RAT)	ACUTE DERMAL (RABBIT)	ACUTE INHALATION (RAT)	LOWEST NOAEL (REPEATED DOSE, RAT)	AQUATIC TOXICITY (96 HRS; FISH)
Lethal dose or concentration (50%)	1288 mg/kg*	2000–20000 mg/kg*	>3900 mg/m^3/1H*	100 mg/kg/day** (hepatotoxicity)	1–12 mg/L*

Notes: *From SLS product manufacturer MSDS (Stepan Company, IL)[5,6]; **From OECD Screening Ingredient Data Set.[8]

Dermal irritation. Dermal toxicity studies demonstrate that 24-hour exposure to a 1–2% (w/w) solution of SLS can increase the transepidermal water loss of the stratum corneum – the outer most layer of the skin – and cause mild yet reversible skin inflammation.[24,25] Human patch tests (typically a 24-hour exposure) confirm that SLS concentrations >2% are considered irritating to normal skin.[2,26,27] Dermal irritation also tends to increase with SLS concentration and the duration of direct contact.[2] In reality, dermal exposure to SLS in cleaning products is more likely to last a matter of minutes rather than hours.[9]

Cleaning products that contain SLS have the potential to be dermal irritants if not formulated properly, but products that contain SLS are not necessarily irritating to the skin.[28,29] Proper formulation development includes strategies for mitigating irritation (like adding cosurfactants) and can produce products with SLS that are mild and nonirritating to the skin. Owing to the irritation potential, however, consumer product manufacturers are required to conduct testing to appropriately characterize the dermal toxicity of the product and label the product with the appropriate warnings and first aid information according to the mandatory labeling requirements of the CPSC.[12]

Another assertion is that SLS is corrosive to the skin.[11,16] Corrosive chemicals are those that cause irreversible damage or destruction of the skin as a result of direct skin contact. Material safety data sheets for SLS do not categorize this chemical as a corrosive material and do not require any special handling precautions.[6–8] As such, statements about SLS being corrosive to the skin are inaccurate.

Oral toxicity. Acute oral toxicity refers to the immediate adverse effects that result from ingesting a substance. The acute oral toxicity of individual ingredients and formulated products is measured in terms of the median lethal dose (LD_{50}), which indicates the quantity by weight (typically in milligrams of substance per kilograms of body weight) required to kill half of the laboratory animals receiving that dose. Ingredients and formulations with an LD_{50} of ≥5,000 mg/kg are classified as nontoxic.[12] The acute oral toxicity of SLS as a raw material is reported to range from 600 to 1,288 mg/kg (in rats), which indicates that SLS is toxic to rats as a standalone ingredient.[6–8]

The acute oral toxicity of SLS is not disputed, but it is relevant to the overall safety review of SLS. It is important to remember that the toxicity of a formulated consumer product is dictated by the formulation as a whole, not by the toxicity of an individual ingredient. This means that while SLS as a raw material at 100% concentration may have a LD_{50} of <5,000 mg/kg, formulations that contain diluted or lesser concentrations of SLS are not necessarily toxic and can even be nontoxic. This holds true for the use of SLS in food products as well and explains why SLS is listed on the U.S. Food and Drug Administration (FDA) list of multipurpose additives allowed to be directly and indirectly added to food.[30] Note, too, that every chemical has a toxic dose, and many common foods can be classified as toxic. For example, sodium chloride (table salt) has an LD_{50} of 3,000 mg/kg, making it moderately toxic by definition.[31]

Chronic toxicity. *Carcinogenicity.* The most egregious claim by far is that SLS is carcinogenic.[16,32] The origin of this claim is uncertain, but it is likely to have derived from multiple misinterpretations of the scientific literature. There is no scientific evidence supporting that SLS is a carcinogen.[33,34] SLS is not listed as a carcinogen by the International Agency for Research on Cancer (IARC); U.S. National Toxicology Program; California Proposition 65 list of carcinogens; U.S. Environmental Protection Agency; and the European Union. In 1998, the American Cancer Society (ACS) published an article attempting to correct the public's misconception of SLS.[32] Regardless, false claims about SLS proliferated throughout the digital media, causing consumers to develop significant concerns about SLS in household cleaning products.

The perception that SLS is carcinogenic is often based on studies that use the ingredient to evaluate the carcinogenicity of other agents. An article written by Birt et al.[36] is commonly cited as supporting the carcinogenicity claim for SLS. However, this is another example of public misinterpretation and the resulting dissemination of inaccurate information. In the study by Birt et al.[35], SLS was used as a vehicle to process the agent being tested. No evidence supporting the carcinogenic effect of SLS was reported. It is apparent that the common use of SLS as a solubilizing agent in toxicology studies has led to the public's confusion around the chronic toxicity of SLS.

Other claims denouncing SLS as a carcinogen point to a chemical reaction between SLS and formaldehyde that creates nitrosamines as a by-product.[32] However, it is not possible for SLS and formaldehyde to react and form a nitrosamine. Nitrosamines contain two nitrogen atoms, but neither SLS nor formaldehyde contain nitrogen atoms. Therefore, the two cannot react to form a nitrogen-containing nitrosamine. Although nitrosamines have been associated with several types of cancer and many are classified by IARC as known, possible, or probable carcinogens depending on the chemical species,[34] they cannot be associated with the presence and use of SLS.

Another carcinogenic by-product, 1,4-dioxane, is falsely associated with SLS.[32] 1,4-dioxane is categorized as *possibly carcinogenic to humans* by IARC,[34] and the potential for some surfactants – like sodium laureth sulfate (also called sodium lauryl ether sulfate or SLES) – to be contaminated with 1,4-dioxane during the ethoxylation process is well established.[36] Barring contamination by manufacturing equipment, surfactants that are not ethoxylated, such as SLS, do not share the same risk of 1,4-dioxane contamination. It is important to note, however, that potential for cross-contamination during manufacturing exists. Manufacturers of SLS and products containing SLS can perform chemical analyses to confirm if there are detectable levels of 1,4-dioxane in the SLS ingredient or formulated consumer product.

Organ toxicity. It is often claimed that SLS *absorbs into the blood stream, builds up in the heart, liver, lungs and brain, and causes damage.*[13,16] Claims of this nature often cite the Cosmetic Ingredient Review (CIR) Final Report on the safety of SLS, which contains an extensive review of the absorption and excretion of SLS in humans and animals.[1] However, the CIR concludes that while SLS can be absorbed through the skin when applied directly, the majority of the material remains in or on the skin surface. SLS that is absorbed into the bloodstream is quickly metabolized by the liver into more water-soluble metabolites that are rapidly excreted through the urine, feces, and sometimes expired breath.[1,22,23,37] There is no evidence in the CIR report or in the scientific literature at large that supports the accumulation of SLS in vital organs and associates it to systemic toxicity or vital organ damage.[22,23,33] As such, accusations that SLS will bioaccumulate in humans and cause organ damage are inaccurate.

Dermatological effects. *Hair loss.* The CIR report[1] is also cited as supporting the claim that SLS can cause hair loss and baldness.[13,16,32] The CIR report states as follows:

> Autoradiographic studies of rat skin treated with radio-labeled Sodium Lauryl Sulfate found heavy deposition of the detergent on the skin surface and in the hair follicles; damage to the hair follicle could result from such deposition.

The report goes on to say that high concentrations of SLS may affect the hair, but no evidence is presented to show that SLS exposure causes hair loss. Rather, the report recommends that cosmetic products applied to the skin not contain concentrations of SLS >1% due to its potential to deposit on hair follicles.[1,2] In addition, the report states that additional research would be required to elucidate the true effects of the deposition. As of 2015, no scientific evidence has been produced to suggest that dermal exposure to SLS causes hair loss.

A study published in 1998 by the *European Journal of Dermatology* is also cited as supporting claims that SLS causes hair loss.[38] This study investigates the effects of oxidative stress on skin irritation and uses SLS as an experimental irritant. There is no discussion of hair loss. As in the CIR report, the researchers of this study[38] identified the deposition of SLS on the root sheath of the hair follicle but did not draw conclusions about the effects of this deposition on the hair. The study[38] in no way suggests that SLS is responsible for, or contributes to, chronic hair loss. In general, no data have been generated to elucidate the long-term effects of SLS deposition on hair follicles, but based on the widespread and long-term use of SLS in hair care products, such an effect is highly unlikely. Overall, claims that associate the use of SLS-containing products with hair loss are not scientifically supported.

Sensitization. Another unsubstantiated claim about SLS is that it can cause severe dermal sensitization.[13,16] A sensitizer is a substance that causes hypersensitivity through an allergic or photodynamic process, which becomes evident on reapplication of the same substance on the skin. There is no scientific evidence to support that SLS has sensitization potential. SLS is not included on any lists of known or suspected sensitizers.[33] Therefore, stating that SLS is a sensitizer is inaccurate.

Other chronic toxicities. To a lesser extent, claims about SLS causing chronic adverse health effects – such as mutagenicity, reproductive and development toxicity, neurotoxicity, and endocrine disruption – have been made without adequate substantiation.[16] Therefore, it is worth mentioning that SLS has no known chronic health effects. According to the National Library of Medicine's TOXNET® database, SLS is not classified as a known or suspected mutagen, reproductive or developmental toxicant, neurotoxicant, or endocrine disruptor.[33]

Environmental Toxicity Profile

Use and disposal of cleaning products release SLS into the environment via household wastewater systems. Therefore, the environmental toxicity profile is an important consideration when evaluating the risks and benefits of using SLS in household cleaning product formulation. Although the environmental toxicity of SLS does not appear to be a point of debate in online communications, a concise review is included to demonstrate the end-use effect of this ingredient.

Aquatic toxicity. Aquatic toxicity refers to the short-term adverse effects that result from the exposure of aquatic life to a chemical or formulation. This type of toxicity is measured in terms of the median lethal concentration (LC_{50}), which indicates the quantity by volume (typically reported as milligrams of substance per liter of water) required to kill half of the experimental population exposed to that dose. Ingredients or formulations with an LC_{50} of ≥100 mg/L are classified as nontoxic to aquatic life.[39]

As a raw material, the LC_{50} for SLS is reported between 1 and 13.9 mg/L after 96 hours, categorizing it as moderately toxic to aquatic life.[6–8,40–44] Like acute oral toxicity, aquatic toxicity values for individual ingredients do not directly correspond with the toxicity of formulated consumer products. This means that while SLS is moderately toxic to aquatic life in its raw material form, product formulations that contain dilutions of SLS are not necessarily moderately toxic and, in fact, can be nontoxic to aquatic life. However, the toxicity of SLS depends largely on the marine species, water hardness, and water temperature.[41,43,44]

By the time cleaning product ingredients reach natural waters, they are mostly degraded. Ecotoxicity studies have determined that a surfactant concentration of 0.5 mg/L of natural water would be essentially nontoxic to fish and other aquatic life under most conditions.[42] It is suggested, however, that chronic toxicity of anionic surfactants occurs at concentrations as low as 0.1 mg/L.[40]

Biodegradability. The ability of a chemical to decompose into simple, nontoxic components under ambient environmental conditions within a short period of time (typically 96 hours) means that it is biodegradable. SLS is readily biodegradable under aerobic and anaerobic conditions and, therefore, does not persist in the environment.[8,37,45] The biodegradation of SLS occurs via hydrolytic cleavage of the sulfate ester bond leaving inorganic sulfate and fatty alcohol. These fatty alcohols undergo oxidation to produce fatty acids, which are degraded by β-oxidation and fully mineralized and incorporated into the biomass.[45] Thus, the decomposed by-products of SLS are benign to the environment.

Biobased content. The biobased content of an ingredient is a primary criterion for formulating sustainable consumer products. The biobased content of an ingredient or formula is the percentage of carbon molecules in the chemical or formula that is derived from a renewable source – such as coconut or palm kernel oil. The biobased content of plant-derived SLS is 100%, which indicates that all of the carbon in the molecule is derived from a plant source rather than a nonrenewable, petroleum source. By comparison, SLES – a surfactant commonly used in household cleaning product formulations – is an ethoxylated surfactant containing carbon molecules derived from petroleum. SLES ethoxylated with petrochemicals has a biobased content of ~76%. From a sustainability and environmental health perspective, sourcing surfactants such as plant-derived SLS avoids incurring the additional environmental and human health impacts caused by the extraction of petroleum and the production of petrochemicals.

Conclusion

The review of SLS toxicity profiles confirms that SLS is an acceptable surfactant for use in household cleaning product formulations from toxicological and sustainability perspectives. Years of anti-SLS campaigns have led to consumer concerns and confusion regarding the safety of SLS. Yet, the primary concern – that SLS has potential for being irritating to the eyes and skin – can be easily addressed by proper formula development and appropriate irritation testing performed by the product manufacturers. SLS is considered a sustainable material because of its 100% biobased content, biodegradability, and low potential to bioaccumulation. Toxicological data support that SLS is safe for use in cleaning products when formulated to minimize its irritancy potential. It is concluded that the use of SLS in cleaning product formulations does not introduce unnecessary risk to consumers or the environment because of the presence of the ingredient, and, if properly formulated and qualified, does not pose danger to human health and safety. Therefore, the perception that SLS is a threat to human health is not scientifically supported, and claims made to the contrary should be regarded as false and misleading.

Author Contributions

CAMB conceived and designed the review and wrote the first draft of the manuscript. HSR, SRL, LBW and KEG contributed to the writing of the manuscript. JLM is a scientific writer and revised the manuscript to its final version. CAMB and JLM jointly made critical revisions to the manuscript. All authors reviewed and approved of the final version.

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