Safety Assessment of Ubiquinone Ingredients as Used in Cosmetics

Status: Final Report
Release Date: April 14, 2022
Panel Meeting Date: March 7-8, 2022

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ABSTRACT

The Expert Panel for Cosmetic Ingredient Safety (Panel) assessed the safety of 4 Ubiquinone ingredients as used in cosmetic formulations. These ingredients are mostly reported to function in cosmetics as antioxidants, while some are also reported to function as skin protectants, skin conditioning agents, and hair conditioning agents. The Panel reviewed relevant data relating to the safety of these ingredients in cosmetic formulations, and concluded these Ubiquinone ingredients are safe in cosmetics in the present practices of use and concentration described in this safety assessment.

INTRODUCTION

This assessment reviews the available safety information of the following 4 Ubiquinone ingredients as used in cosmetic formulations:

Disodium Ubiquinone	Ubiquinol
Hydroxydecyl Ubiquinone	Ubiquinone

According to the web-based *International Cosmetic Ingredient Dictionary and Handbook* (wINCI; *Dictionary*), these Ubiquinone ingredients are reported to function in cosmetics as antioxidants; some are also reported to function as skin protectants, skin conditioning agents, and/or hair conditioning agents (Table 1).[1] Ubiquinone is commonly known as coenzyme Q10.

This safety assessment includes relevant published and unpublished data that are available for each endpoint that is evaluated. Published data are identified by conducting an exhaustive search of the world's literature. A listing of the search engines and websites that are used and the sources that are typically explored, as well as the endpoints that the Expert Panel for Cosmetic Ingredient Safety (Panel) typically evaluates, is provided on the Cosmetic Ingredient Review (CIR) website (https://www.cir-safety.org/supplementaldoc/preliminary-search-engines-and-websites; https://www.cir-safety.org/supplementaldoc/cir-report-format-outline). Unpublished data are provided by the cosmetics industry, as well as by other interested parties.

Toxicological assessments of Hydroxydecyl Ubiquinone were issued by the European Medicines Agency and by the Australian Government Department of Health.[2,3] Data summaries are available on the respective websites, and when deemed appropriate, information from the summaries has been included in this report.

CHEMISTRY

Definition and Structure

The definitions and chemical structures of the Ubiquinone ingredients included in this report, as given in the *Dictionary*, are provided in Table 1. These ingredients, which are a class of homologous benzoquinones, aptly named for their ubiquitous existence in the vast majority of living organisms,[4] have been grouped together because they share a 2,5-cyclohexadiene-1,4-dione core, with various alkyl chain substituents at the 2 position of the cyclohexadiene, to comprise the salts or metabolites, thereof.

Ubiquinone (CAS No. 303-98-0) is the organic compound which is depicted in Figure 1.[1] While some of the technical names for Ubiquinone provided in the *Dictionary* may seem to suggest a number of isoprenoid units other than 10 (e.g., Ubiquinone 50; although, the "50" therein refers to the number of carbon atoms, and is thus 10 isoprenoid units), the structure and formula provided in the monograph indicate 10 such repeat units.

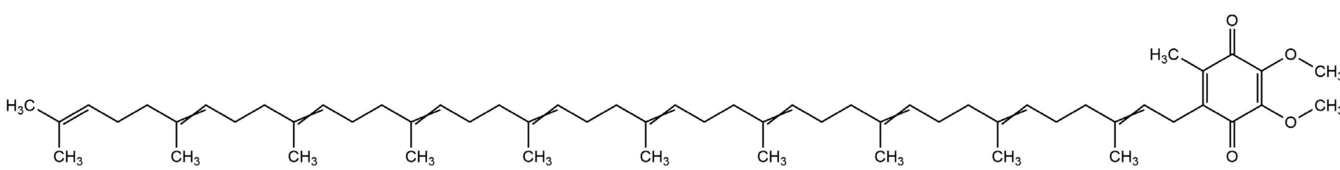


Figure 1. Ubiquinone

Many biological functions involving Ubiquinone result, in part, because of the redox reactions to/from Ubiquinol (CAS No. 992-78-9), through the radical intermediate, ubisemiquinone, as seen in Figure 2.[5]

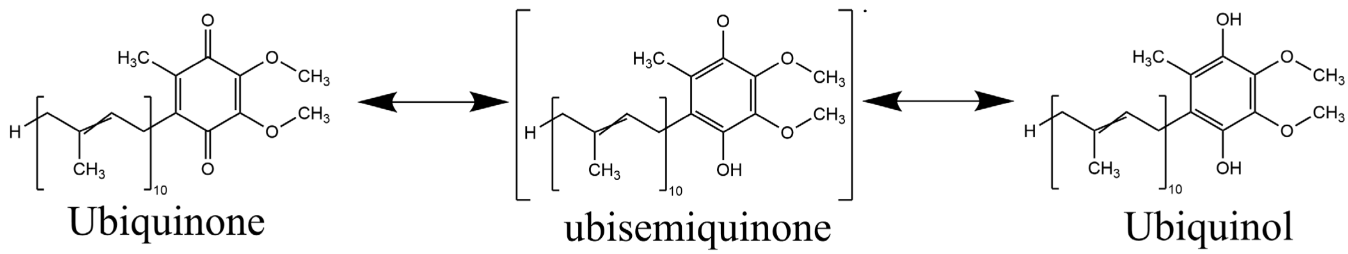


Figure 2. Redox between Ubiquinone and Ubiquinol

Hydroxydecyl Ubiquinone, however, is structurally dissimilar to the other 3 ingredients herein (Figure 3). This ingredient shares a benzoquinone core structure, as well as 1 methyl and 2 methoxy functional groups, in common with the other 3 ingredients. However, wherein the other 3 ingredients have a polyisoprenoid sidechain, the Hydroxydecyl Ubiquinone sidechain comprises a simple, 10-carbon alkyl chain with a terminal alcohol group.

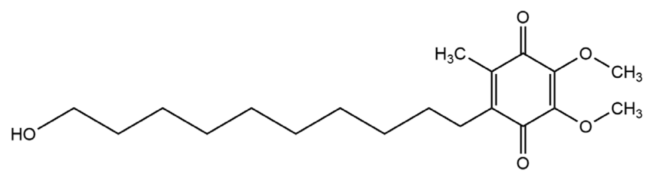


Figure 3. Hydroxydecyl Ubiquinone

Chemical Properties

These benzoquinone homologs consist of a redox active quinoid moiety, and a hydrophobic side chain comprising 6 to 10 isoprenoid units, depending on the species. In rats and mice, coenzyme Q_9 is the predominant form. In humans, the predominant form of Ubiquinone is coenzyme Q_{10}, referring to a side chain of 10 isoprenoid units. Disodium Ubiquinone, Hydroxydecyl Ubiquinone, Ubiquinol, and Ubiquinone have partition coefficients of 20.23, 3.88, 23.74, and 16.51, respectively (log K_{ow}; estimated).[6] Both Ubiquinol and Ubiquinone are sparingly soluble in water.[7,8] The chemical properties of these ingredients are further outlined in Table 2**.**

Natural Occurrence

Human skin is known to contain both enzymatic and non-enzymatic (antioxidant) mechanisms for protecting itself from oxidative stress.[9] There is 10 times more Ubiquinol (3.53 vs. 0.35 nmol/gm), and almost twice as much Ubiquinone (4.12 vs. 2.86 nmol/gm), in the human epidermis, compared to the dermis.[10] Ubiquinone and Ubiquinol content is known to peak in human tissue in early adulthood, and decline with age.[9] The plasma concentration of Ubiquinone in healthy humans ranges from 0.20 to 1.91 µmol/l, and the total body pool is estimated to be approximately 0.5 - 1.5 g.[11]

Method of Manufacture

Most of the methods of manufacture summarized below are general methodologies, and it is unknown if they apply to cosmetic ingredient manufacturing.

Ubiquinone

In 1957, Ubiquinone was isolated from beef heart mitochondria and was first chemically synthesized in 1958.[12,13] Ubiquinone is also found in a wide variety of dietary sources such as oily fish, organ meats, whole grains, and vegetables.[14]

Ubiquinone is produced outside the body by one of two methods, either chemical synthesis or microbial fermentation.[15-19] Chemical synthesis occurs sequentially via creation of a quinonoid ring, synthesis of decaprenyl diphosphate, and quinonoid ring modification, each of which is catalyzed by various enzymes, using sources like plant-derived solanesol.[15,20-22] Microbial fermentation is considered the most efficient and environmentally benign means of producing Ubiquinone as the process is easier to control, can be executed on a large scale with less time and resources, and requires less use of solvent.[23,24] The gram-negative bacterium, *Agrobacterium tumefaciens,* is often used for its relatively high synthesis rates.[16] According to one supplier, Ubiquinone produced via yeast fermentation can result purely in the all-*trans* form (does not contain any *cis*-alkenes).[19]

A few other natural producers of Ubiquinone include *Schizosaccharomyces pombe* (fission yeast), *Sporidiobolus johnsonii*, and *Rhodobacter sphaeroides* (a photosynthetic bacterium).[24] During the course of Ubiquinone production, it is possible for Ubiquinone species of varied isoprenoid chain lengths, such as coenzyme Q8 and coenzyme Q9, to be produced.[25] Natural or "native" producers of Ubiquinone do not produce other Ubiquinone species of varied chain length; however, in spite of initially higher Ubiquinone yields, production has not been optimized in these organisms. Heterologous "non-native" producers of Ubiquinone, such as *Escherichia coli*, *Saccharomyces cerevisiae* (yeast), and plants provide the advantage of genetic manipulation to optimize Ubiquinone yields.

High hydrostatic pressure treatment, ultraviolet light (UV), and diethyl sulfate treatment were utilized to induce mutagenesis during the submerged microbial fermentation process of Ubiquinone production from *A. tumefacians*, to test if mutant strains would effect higher yields of Ubiquinone than wild-type strains.[23] A mutant strain PK38 was shown to increase Ubiquinone production by 52.83% compared to the original strain. Exponential feeding, fed-batch culture strategy, using 30 µl sucrose, produced a final cell biomass, Ubiquinone production, and specific Ubiquinone production increase of 126.11, 173.12, and 22.76 %, respectively, compared to those of batch cultures.

Impurities

Ubiquinone

In a study assessing the ability of non-aqueous, reversed phase, high performance liquid chromatographic (NARP-HPLC) to distinguish Ubiquinone from its process-related impurities during pharmaceutical manufacturing, researchers detected 2,3-dimethoxy-5-methyl-*p*-benzoquinone, solanesol, solanesyl acetone, and isodecaprenol at trace amounts, with up to 100% recovery of Ubiquinone.[26] While analyzing the degradation products of Ubiquinone, through exposure to triethylamine (a base), under heat and ethanol, researchers discovered two unknown impurities, with isomeric qualities.[27]

According to data received from the industry, Ubiquinone produced by yeast fermentation, is purely in the all-*trans* form (does not contain all- or partially-*cis*-isomers).[19] The content is > 98% coenzyme Q10, with coenzyme Q9 and coenzyme Q11 as the two major impurities. The same source identifies additional impurities, which may occur in Ubiquinone: 2,3-dimethoxy-5-methylbenzene-1,4-diol; ubiquinone-7; ubiquinone-8, ubiquinone-9 (detected at < 0.3%), ubicromenol, and ubidecarenone (*Z*)-isomer.

Function in Mitochondrial Electron Transport Chain

Ubiquinone acts as a cofactor in the bioenergetic process of electron transfer in the mitochondrial electron transport chain, which is essential for adenosine triphosphate (ATP) production.[22] As an antioxidant, in its reduced form of Ubiquinol, it protects against free radical damage, functions in cell signaling and gene expression, and is capable of regenerating other antioxidants, such as tocopherol and ascorbate.[28] Due to the involvement of Ubiquinone and Ubiquinol in cellular energy production and respiration, Ubiquinol is present at higher concentrations than Ubiquinone in mitochondria-rich tissue, such as the liver, heart, kidney, and spleen, where it provides protection against oxidation in DNA and cell membrane lipids and proteins.[22,29]

Endogenously, Ubiquinone is produced via the mevalonate pathway, in either the mitochondria or Golgi apparatus, of human cells.[24] Acetyl coenzyme A (acetyl-CoA) is converted during an isopentyl-5-diphosphate (IPP)-limited cascade of 3-hydroxy-3-methylglutaryl-CoA (HMGC) catalysis to decaprenyl diphosphate synthase (DPS), which interacts with tyrosine to produce Ubiquinone. The chemical precursors for the quinone head and isoprene tail vary across species.

USE

Cosmetic

The safety of the cosmetic ingredients addressed in this assessment is evaluated based on data received from the US Food and Drug Administration (FDA) and the cosmetics industry on the expected use of these ingredients in cosmetics. Use frequencies of individual ingredients in cosmetics are collected from manufacturers and reported by cosmetic product category in the FDA Voluntary Cosmetic Registration Program (VCRP) database. The cosmetic product categories named in the VCRP database indicate the intended uses of cosmetic ingredients, and are identified in 21 CFR Part 720. Data are submitted by the cosmetic industry in response to a survey conducted by the Personal Care Products Council (Council) of maximum reported use concentrations, also by product category. Neither the categories provided by the VCRP, nor those provided by the Council survey, include a designation for use via airbrush application. Airbrush devices, alone, are within the purview of the US Consumer Product Safety Commission (CPSC), while ingredients used in airbrush devices are within the jurisdiction of the FDA. As airbrush technology use for cosmetics has neither been evaluated by the CPSC, nor the use of cosmetic ingredients in airbrush technology by the FDA, no US regulatory authority has evaluated the safety of this delivery methodology for cosmetic ingredients. Moreover, no consumer habits and practices data are available to evaluate the risks associated with this use type.

According to 2022 VCRP survey data, Ubiquinone is reported to be used in 221 cosmetic products, of which 208 are leave-on products (Table 3).[30] The results of the concentration of use survey conducted by the Council in 2018 (and submitted to CIR in 2019) indicate that the maximum leave-on use concentration in this ingredient group is 0.05% for Ubiquinone, in body and hand products.[31] No concentrations of use were reported for Hydroxydecyl Ubiquinone or Ubiquinol in industry surveys conducted in 2018[31] and 2020[32], and no uses were reported in the VCRP or the industry survey for Disodium Ubiquinone.

Ubiquinone has reported uses in products that may come in contact with the eyes; for example, Ubiquinone is used at up to 0.02% in eye shadows. Ubiquinone has reported use in oral hygiene products, which may lead to incidental ingestion, and bath soaps and detergents, which may lead to exposure to mucous membranes; concentration of use data were not reported in the industry survey for either of these reported uses.

Additionally, although products containing some of these ingredients may be marketed for use with airbrush technology, this information is not available from the VCRP or the Council survey. Without information regarding the frequency and concentrations of use of these ingredients (and without consumer habits and practices data related to this use technology), the data are insufficient to evaluate the safety thereof in airbrush applications.

None of the Ubiquinone ingredients named in this report are restricted from use in any way under the rules governing cosmetic products in the European Union.[33]

Non-Cosmetic

Ubiquinone has been approved in Japan for use as a congestive heart failure drug since 1974, and as a food ingredient since 2001.[13,34] Hydroxydecyl Ubiquinone has been approved for pharmaceutical use in Japan since 1984.[35]

Ubiquinone was also listed in the *European Pharmacopeia* in 2001 and the *United States Pharmacopeia* in 2002.[15] The FDA has not approved the use of Ubiquinone as a drug; however, since the enactment of the Dietary Supplement Health and Education Act of 1994, use as a dietary supplement has expanded.[17] Ubiquinone is commonly sold as a dietary supplement under the name of coenzyme Q10, referring to its biological function and structure.[36] Although consumed at much higher doses in those with pathological conditions, coenzyme Q10 is typically sold at doses of 100 - 200 mg.[36] In many clinical trials, Ubiquinone has been tested for the treatment of heart disease, hypertension, breast cancer, Alzheimer's disease, and Parkinson's disease, and has been shown to be well tolerated at doses as high as 1200 mg/d.[4] Ubiquinol and Ubiquinone have been designated orphan drug status, in accordance with [21CFR316], and are pending FDA orphan indication approval, for the treatment of pediatric congestive heart failure (since 2004), as well as individually, for the treatment of Huntington's disease (in 2004) and mitochondrial cytopathies (since 1999).[37]

TOXICOKINETIC STUDIES

Dermal Penetration

In Vitro

Ubiquinone

Dermally applied Ubiquinone (amount not specified), in ethanol, was able to penetrate the stratum corneum of live porcine skin, and approximately 20% and 2% of the administered dose was found in the epidermis and dermis, respectively.[9] (No further details were provided). A solution of 1% Ubiquinone, in olive oil, was topically applied to rats (amount not specified); levels in the skin were 8 µg/g after 2 h, and 15 µg/g after 4 h.[16] A dose-response relationship was observed between the amount of Ubiquinone applied and the concentration in skin. (No further details provided).

Penetration of Ubiquinone, mixed in either a microemulsion formulation or a hydrophilic cream, was examined in female mammary tissue, and evaluated using a high performance liquid chromatography (HPLC) method.[38] A 20 mg dose of each formulation was applied evenly to the stratum corneum/donor compartment side of a circular piece of excised female mammary tissue (2 cm in diameter, 3.14 cm^2) mounted in Franz in vitro diffusion cells. The dermal side of the skin and the acceptor compartment were separated by filter gauze; the acceptor compartment was filled with 20 ml distilled water, and cell hydrodynamics were maintained with circulating water. The skin samples were incubated for 0.5, 2, and 6 h, after which the test formulation remaining on the skin was carefully removed by a cotton swab and three 6-mm diameter discs (0.2827 cm^2). These discs were sectioned into different slices using a cryo-microtome; the upper 10 µm slice represented the stratum corneum, 4 subsequent 20 µm slices were considered viable epidermal layer, and each of the dermis sublayers were represented by five 40 µm slices. Ubiquinone was extracted from each skin layer with 0.1 ml acetonitrile by shaking for 1 h, and analyzed by HPLC. After 6 h, more than 90% of the applied Ubiquinone in the hydrophilic cream penetrated into viable epidermis, compared to only 60% penetration of Ubiquinone in the microemulsion formulation. The authors surmised that this effect was attributed to the lipophilic components of the microemulsion formulation (including 40% pentylene glycol), which the highly lipophilic Ubiquinone bound to. Additionally, the 2-ethyylhexyl laurate (10 %) appeared to work as a penetration enhancer for Ubiquinone in the hydrophilic cream.

Absorption, Distribution, Metabolism, and Excretion (ADME)

Ubiquinol and Ubiquinone are known to be poorly soluble in water, and therefore have limited bioavailability in the body, unless dissolved in another lipophilic substance, or consumed with a meal containing fat.[39,40] The maximum serum concentration of orally ingested Ubiquinone being captured between 6 - 8 h (T_{max}), on average, in solubilized formulations, suggests slow absorption of this large and hydrophobic molecule in the intestine.[28,41] Although structurally distinct, Ubiquinol is the predominant metabolite of Ubiquinone, and has higher bioavailability than Ubiquinone.[42] Most endogenous Ubiquinone is reduced to, and exists as, bioreactive Ubiquinol in the mitochondria, endoplasmic reticulum, lysosomes, peroxisomes, and plasma membranes of eukaryotic cells.[11,28,29,42,43]

Animal

Oral

Hydroxydecyl Ubiquinone

Hydroxydecyl Ubiquinone metabolism is characterized by oxidation of the isoprenoid side chain, β- oxidation, reduction of the quinone ring, and subsequent conjugation to form 1- or 4-phenyl sulfates or glucuronides of the hydroquinone derivatives.[35] These metabolites are generally regarded as pharmacologically inactive. In a pharmacokinetic study performed in rats and dogs, peak plasma Hydroxydecyl Ubiquinone levels in rats plateaued at 8 h and later reduced, with a half-life of 4.5 h.[35] In dogs, no Hydroxydecyl Ubiquinone level plateau occurred, and plasma levels showed a biphasic decline with half-lives of 2.2 and 15.4 h. In both species, elimination was almost complete in 48 h.

Ubiquinone

In a pharmacokinetic study, male Sprague-Dawley rats had 3.33 mg/kg bw of lipid-soluble Ubiquinone, mixed with water, delivered directly to the stomach using an oral tube.[39] Ubiquinone uptake rates peaked at 10 h after intake at 0.183 ± 0.017 µg/ml. In a 1 – yr chronic toxicity study of Ubiquinone, Wistar rats were administered 100, 300, 600, or 1200 mg/kg/d.[44] At the end of dose administration, Ubiquinone was found to exhibit a half-life range of 10.7 to 15.2 h in rats.

Other Routes

Ubiquinone

In a study examining the ratio of oxidized and reduced forms of Ubiquinone in living systems, Wistar rats were dosed with a one-time intravenous injection of solubilized Ubiquinone (10 mg/kg; solvent not provided), and 10 blood samples were taken 0.1 - 48 h after injection.[43] The blood samples were immediately centrifuged, frozen, and stored at -20 °C, for up to 2 wk. Results showed an increase in Ubiquinol, up to 89%, 1 d after injection, supporting the notion that Ubiquinol represents 90% of plasma Ubiquinone. However, 2 d after administration, serum Ubiquinone levels were still higher than at baseline.

Human

Oral

Hydroxydecyl Ubiquinone

Experimental data have shown that Hydroxydecyl Ubiquinone passes the blood-brain barrier and has a high first pass metabolism.[45] Most of the ingested dose is excreted through the kidneys as conjugates and metabolites of Hydroxydecyl Ubiquinone.

Healthy male subjects were assigned to receive a single oral dose of 150 mg (Group A: 13 men) or 750 mg (Group B: 12 men) Hydroxydecyl Ubiquinone after eating breakfast.[35,46] After a washout period of 7 d, Group A received the same dose 3 times a day, for a total of 450 mg/d, while Group B received a 750 mg dose three times a day, for a total of 2250 mg/d, for a period of 14 d. After a single oral administration of 150 or 750 mg, Hydroxydecyl Ubiquinone values peaked in plasma within 2 h on average. During repeated dosing in both groups, the pre-dose plasma concentrations were only slightly above the lower limits of quantification, indicating that there was no relevant accumulation of the test substance. The primary metabolites resulting from Hydroxydecyl Ubiquinone oxidation, which are found in free and conjugated (C) forms, are 6-(9-carboxynonyl)-2,3-dimethoxy-5-methyl-1,4-benzoquinone (QS10), 6-(7-carboxyheptyl)-2,3-dimethoxy-5-methyl-1,4-benzoquinone (QS8), 6-(5-carboxypentyl)-2,3-dimethoxy-5-methyl-1,4-benzoquinone (QS6), and 6-(3-carboxypropyl)-2,3-dimethoxy-5-methyl-1,4-benzoquinone (QS4). After single and repeated oral administration of Hydroxydecyl Ubiquinone, most of the test substance (~ 50%) was excreted in urine as free and conjugated QS4 (40%), QS6 (6%), QS10 (< 1%), and Hydroxydecyl Ubiquinone (< 1%). At the 750 mg dose, a slightly higher proportion of free and conjugated metabolites were excreted (~ 60%), with 50% QS4, 9% QS6, 1.5% QS10, and < 1% of Hydroxydecyl Ubiquinone.

Ubiquinol

Eighty healthy men and women received either a placebo, or a 90, 150, or 300 mg oral dose of Ubiquinol, emulsified in diglycerol monooleate, rapeseed oil, soy lecithin, and beeswax, with 180 ml water, for up to 28 d.[47] The Ubiquinol half-life in subjects who received a single dose of 150 or 300 mg was estimated to be 48 h. The maximum concentration (C_{max}) of mean plasma Ubiquinol 6 h after administration was 1.88 µg/ml for the 150 mg group, and 3.19 µg/ml for the 300 mg group; the area-under-the-curve over 48 h ($AUC_{(0-48h)}$) was 74.61 µgh/ml and 91.76 µgh/ml, respectively. Plasma Ubiquinol levels showed a non-linear dose-dependent increase, reaching steady-state (2.1 - 2.8-fold increase) around 2 wk after treatment. Slight increases in eosinophil percentage, and low-density lipoprotein levels of 2 males in the 150 mg dosage group were not considered clinically significant. One subject in the 300 mg group withdrew on day 1 due to diarrhea and leukocytosis, both unrelated to the test substance; other events were mild and moderate in severity and were not of clinical significance.

Ubiquinone

Twenty healthy males were administered, either fasting or post-prandially, 60 mg lipid-soluble Ubiquinone capsules along with 200 ml of water.[39] Blood samples were collected before Ubiquinone intake and up to 24 h after intake to measure serum levels of Ubiquinone. In the fasting group, the uptake rate was 0.018 ± 0.006 µg/ml/h, while in the post-prandial group the uptake rate was 0.026 ± 0.008 µg/ml/h. According to another study, the absorption rate of Ubiquinone is about 3%, when consumed with food.[39] In a double-blind, single-dose, bioavailability study, 5 healthy subjects from both sexes consumed 120 mg lipid-soluble Ubiquinone, in capsule form, on an empty stomach before breakfast.[40] The area-under-the-curve over 10 h ($AUC_{(0-10h)}$) was determined to be 4.9 µg/ml/h. In a pharmacokinetic study, a single, oral dose of 100 mg deuterium-labelled Ubiquinone was administered to 16 healthy male subjects and exhibited an elimination half-life of 33.19 ± 5.32 h.[48]

TOXICOLOGICAL STUDIES

Acute Toxicity Studies

The acute oral toxicity studies summarized below are described in Table 4.

The acute oral LD_{50} of Hydroxydecyl Ubiquinone was determined to be > 10,000 mg/kg in mice and male rats, and ~ 10,000 mg/kg in female rats.[49,50] The acute oral LD_{50} of Ubiquinone in mice was reported to be > 4000 mg/kg[34] and >20,000 mg/kg,[51] while, in rats, the highest LD_{50} value was determined to be > 5000 mg/kg.[21,34]

Short-Term, Subchronic, and Chronic Toxicity Studies

Details of the short-term, subchronic, and chronic oral toxicity studies summarized below are provided in Table 5.

In a 4-wk study, Wistar rats were administered up to 500 mg/kg/d Hydroxydecyl Ubiquinone, via gavage.[2] Dose-dependent increases in the incidence of/severity of forestomach submucosal inflammation, erosions, ulcerations, and hyperkeratosis were observed. In another study, juvenile rats dosed at up to 1000 mg/kg/d Hydroxydecyl Ubiquinone for 4 wk exhibited slight reduction of body weight in the mid- and high- dose groups, as well as an increased incidence and severity of hyaline droplet accumulation in the renal tubules, and reversible lowered bone density; the no-observed-adverse-effect level (NOAEL) was determined to be 200 mg/kg/d.[3] The non-toxic oral dose of Hydroxydecyl Ubiquinone was determined to be 500 mg/kg/d in rats, administered an unspecified dose over 5 wk.[49] The non-toxic, oral dose of Hydroxydecyl Ubiquinone was determined to be 100 mg/kg/d in in a 5-wk study of Beagle dogs dosed at up to 500 mg/kg/d.[49] In two studies, 5-wk and 26-wk, using rats, the non-toxic dose for Hydroxydecyl Ubiquinone was determined to be 500 mg/kg/d and 20 mg/kg/d, respectively.[49] Gastric irritation, mainly in the form of epithelial cell hyperplasia, histopathological abnormalities in the forestomach, and a general reduction of weight, was observed in CD-1 mice which were administered up to 2000 mg/kg/d Hydroxydecyl Ubiquinone for 13 wk.[3] Wistar rats dosed with up to 1000 mg/kg/d Hydroxydecyl Ubiquinone for 26 wk exhibited mucosal thickening, hyperkeratosis, red spots, hyperplasia, necrosis, edema, and ulceration in the forestomach.[3] These effects were considered reversible and rodent-specific, and therefore of limited toxicological relevance. In a 39-wk study, Beagle dogs (number not specified) were administered 500, 750, or 1000 mg/kg/d Hydroxydecyl Ubiquinone over 39 wk, via gavage.[2,3] Aside from a dose-dependent increase in gastrointestinal disturbances, as well as reduced heart rate in all groups, mild liver hypertrophy and pulmonary hyperplasia in a few animals in the 1000 mg group, no patterns were evident and these results were not considered toxicologically significant.

Groups of 10 Sprague-Dawley rats were administered 0, 300, 600, or 1200 mg/kg/d Ubiquinol, in corn oil, via gavage, for 13 wk.[29] Statistically significant increases in aspartate aminotransferase, alanine aminotransferase, and lactate dehydrogenase activity were observed in rats dosed with > 300 mg/kg Ubiquinol; prothrombin time and activation partial thromboplastin time were within in-house historical control data. Histopathological examinations revealed test-article related effects in the spleen, mesenteric lymph, and livers of females, as well as fine vacuolation of Kupffer cells in multiple females dosed with > 300 mg/kg Ubiquinol. No deaths or adverse clinical effects were observed during treatment, and the NOAEL was conservatively estimated to be 600 mg/kg/d in males and 200 mg/kg/d in females.

In a follow-up study, groups of 10 female Sprague Dawley rats were administered 0, 75, 150, 200, 300, or 1200 mg/kg/d Ubiquinol, in corn oil, via gavage, for 13 wk, with 1200 mg/kg/d Ubiquinone as a reference control.[29] No deaths or toxicologically significant changes related to the test material were observed. Groups of 3 Beagle dogs received doses of 0, 150, 300, or 600 mg/kg/d Ubiquinol, in gelatin, via gavage, for 13 wk, with 600 mg/kg/d Ubiquinone as a reference control.[29] Soft feces were observed in the 300 and 600 mg/kg/d Ubiquinol groups, and estrus hemorrhage in 1 female each in the control and 300 mg/kg Ubiquinol groups. Vomiting was observed in all dosage groups, while statistically significant decreases of eosinophils in males in the 150 and 600 mg/kg group, and platelet counts in females in the 300 mg/kg group were observed; however, these values were not considered test article related and were within testing facility ranges. The NOAEL for Ubiquinol was determined to be 600 mg/kg/d in Beagle dogs.

In a 4-wk study, dosing cRj Wistar rats with 1000 mg/kg Ubiquinone in corn oil, via gavage, did not produce noticeable changes in overall condition, body weight gain, or food consumption, in comparison to controls.[21] Upon necropsy in the Ubiquinone-treated group, one male had enlarged adrenals, and one male had tan-colored lungs. One female from the control group, and several males and females from the Ubiquinone-treated group, also exhibited hemorrhagic and localized pulmonary lesions. In oral studies with Ubiquinone in which rats were dosed for 30 d (up to 2250 mg/kg/d, via gavage) or 5-wk (up to 1000 mg/kg/d), no mortality, noticeable changes, or toxic effects were reported.[34,51] Sprague-Dawley rats received doses of 0, 500, 1500, or 3000 mg/kg/d Ubiquinone, in 0.5% hydromethylfibrin, over 90 d.[14] Statistically significant changes in males included body weight decreases in the 1500 mg/kg group, decreases of red blood cells and hemoglobin in the 500 and 1500 mg/kg groups, white blood cell increases in all dosage groups, and triglyceride decreases in the 1500 and 3000 mg/kg groups, while, for females, ovary weights were slightly decreased in the 1500 mg/kg group, and hematocrit levels were decreased in the 1500 and 3000 mg/kg groups. Groups of 10 Sprague-Dawley rats were dosed with 1200 mg/kg/d Ubiquinone for 13 wk, and served as a reference control.[29] Two males and 3 females exhibited a yellow focus in the lung, mild granuloma of the liver was present in females, and an accumulation of foam cells in lung alveoli was observed in 2 males and 3 females. In another 13-wk study of Sprague-Dawley rats, the NOAEL for Ubiquinone was determined to be > 1200 mg/kg/d.[17] In a 52-wk study, groups of 19 Sprague-Dawley rats/sex were dosed with up to 1200 mg/kg/d of Ubiquinone.[44] One female and 3 males from the 600 mg/kg/d group died during weeks 33, 38, 48, and 52. One male from the 1200 mg/kg/d group died of malignant lymphoma during week 33. Ubiquinone accumulated in the liver during dosing; however, levels returned to pretreatment levels in the recovery animals within 10 d of stopping treatment. In white rabbits, no toxic effects and no microscopic or gross lesions were found in animals dosed for 23 d with up to 600 mg/kg Ubiquinone.[34] Groups of 3 Beagle dogs dosed with 600 mg/kg/d Ubiquinone in corn oil for 13 wk (as a reference control) exhibited soft feces with traces of the test article, vomiting, and a statistically significant increase in neutrophils.[29] A dark red focus of the heart was observed in 1 male, while 1 male and 1 female exhibited an enlarged liver. Opacity of the posterior lens capsule was observed in 1 female, which also occurred in 1 male and 1 female from the control group. Groups of 4 Beagle dogs, which were dosed with 1200 or 1800 mg/kg/d Ubiquinone in gelatin capsules, for 39 wk, had unabsorbed Ubiquinone in stool, and vomiting occurred in all dogs exposed to the highest dose.[52] No deaths occurred during treatment. A white focus was observed in the lungs of one control female dog, and, one male dog from the 1200 mg/kg/d group. These gross pathological findings were not considered toxicologically significant.

DEVELOPMENTAL AND REPRODUCTIVE TOXICITY STUDIES

Details of the developmental and reproductive toxicity studies summarized below are provided in Table 6.

No adverse effects on fertility or reproductive performance were observed in a study in which male and female Wistar rats were dosed orally with up to 500 mg/kg bw Hydroxydecyl Ubiquinone prior to mating, during gestation, and until day 22 post-partum. [49] In several other studies, no statistically significant adverse effects upon reproductive performance or fetal development were seen in rats dosed at up to 1000 mg/kg/d Hydroxydecyl Ubiquinone, although a higher incidence of post-implantation loss was reported in some studies (details not provided).[2,3] The NOAELs, based on body surface area comparisons, were determined to be up to 1000 mg/kg/d for embryofetal development, and 500 mg/kg/d and 1000 mg/kg/d, for male and female fertility, respectively.[3] The offspring of rabbits that were dosed with up to 150 mg/kg/d Hydroxydecyl Ubiquinone displayed chromaturia in the highest dosage group.[2] In Japanese rabbits dosed at up to 500 mg/kg/d Hydroxydecyl Ubiquinone, one abortion was observed in the highest dosage group, but was not considered significant due to the spontaneous abortion rate in the animal strain; no statistically significant embryofetal differences were reported between controls and treated groups.[3] No treatment-related changes were observed in the F_1 generation, or in the dams, of rats dosed at up to 500 mg/kg/d Hydroxydecyl Ubiquinone.[2,3] The NOAEL for rat pup development was determined to be 500 mg/kg/d Hydroxydecyl Ubiquinone.[3]

Treatment with Ubiquinone had no effect on fetal death, weight, or postnatal toxicity in primigravid mice (strain and number not specified) dosed at up to 600 mg/kg/d, from day 7 to day 13 of gestation.[34] Groups of 10 male mice were given up to 10,000 mg/kg bw Ubiquinone, via gavage, for 5 d, followed by a 35-d latency period, to test for defects in sperm morphology.[51] No significant differences were found in the incidence of sperm abnormalities between Ubiquinone-treated mice and the negative controls (treated with corn oil). Except for an increase in seminiferous epithelium heights, no biochemical, histological, or morphological differences were observed between 8 male Wistar rats dosed at 10 mg/kg bw/d Ubiquinone for 14 d and negative control and vehicle control groups.[53] Treatment with Ubiquinone had no effect on fetal death, weight, or postnatal activity in primigravid rats dosed at up to 600 mg/kg/d, from day 9 to day 15 of gestation.[34]

GENOTOXICITY

Details of the genotoxicity studies summarized below are described in Table 7.

Positive mutagenic responses in L5178Y TK +/- mouse lymphoma cells tested with Hydroxydecyl Ubiquinone were not reproducible, dose-related, or statistically significant.[3] In a chromosomal aberration test with Hydroxydecyl Ubiquinone in human peripheral lymphocytes, positive results were attributed to the redox properties of test substance, and the test substance was not considered clastogenic.[3] Ubiquinol was not genotoxic, with or without metabolic activation, in an Ames test at up to 5000 µg/plate, or in a chromosomal aberration test using Chinese hamster lung (CHL/IU) cells at up to 5000 µg/ml.[42] Similarly, Ubiquinone was not genotoxic with or without metabolic activation in multiple Ames tests, at up to 5000 µg/plate, or in chromosomal aberration tests using CHL/IU cells at up to 5000 µg/ml.[15,18,34,51,54] In vivo, no genotoxicity was observed in several micronucleus tests with Hydroxydecyl Ubiquinone, at up to 5000 mg/kg/d (in mice),[2] Ubiquinol, at up to 2000 mg/kg/d (in rats),[42] or Ubiquinone, at up to 10,000 mg/kg/d (in mice).[34,51]

CARCINOGENICITY STUDIES

Hydroxydecyl Ubiquinone

ICR mice (number not specified) were administered a daily dose of 650, 1280, or 2000 mg/kg Hydroxydecyl Ubiquinone via diet for 103 wk.[3] Dosing had no effect on mortality/survival rates. Treatment with Hydroxydecyl Ubiquinone did not influence the incidence, time of onset, location, size, or multiplicity of palpable masses. No increase in the incidence of forestomach tumors was observed. Mice in the mid- and high-dose groups exhibited a low incidence of benign tumors, including hemangioma and leiomyoma, and malignant sarcomas, including fibrosarcoma, leiomyosarcoma, and endometrial sarcoma. These incidences were within the historical ranges of the testing facility for this mouse strain.

Similarly, Sprague-Dawley rats (number not specified) were administered a daily dose of 500 or 1000 mg/kg Hydroxydecyl Ubiquinone via diet for 104 wk.[3] Dosing had no effect on mortality/survival rates. Gross observations of yellow, thickened mucosa correlated with an increased incidence of squamous cell hyperkeratosis; gastritis, forestomach erosions, and basal cell hyperplasia were also observed. Due to the forestomach being a rodent-specific organ, the researchers stated that these findings were not considered clinically relevant. Incidences of lung alveolar carcinoma, adrenal carcinomas, liver and pancreas sarcomas, squamous cell papillomas, thyroid follicular cell carcinomas, and thyroid C-cell adenomas were also observed. (Details on occurrence by dosage group not provided). The researchers stated that the neoplasms were only reported in males, and that the incidences of these neoplasms were below the spontaneous incidence rate for this strain and were without a dose-dependent relationship.

OTHER RELEVANT STUDIES

Depigmentation

Ubiquinone

Vitiligo, a skin disorder characterized by depigmentation, is known to result from oxidative/nitrative stress in the epidermis and body.[55] Fifteen previously unaffected patients presented with vitiligo after daily use of over-the-counter Ubiquinone-containing skin preparations (concentrations not reported). Clinicians suspected that a small percentage of the Ubiquinone had oxidized to yield hydrogen peroxide, a skin-bleaching agent, causing depigmentation in susceptible individuals. Chemical reduction of the epidermal hydrogen peroxide was achieved by treating patients with topical application of narrowband, mid-wavelength UV (UVB)-activated propseudocatalase cream (PC-KUS), resulting in eventual repigmentation. The authors concluded that the concentration of Ubiquinone use in cosmetics or supplements should be carefully considered, especially in individuals who are susceptible to reactive-oxygen-species (ROS)-triggered-vitiligo.

The effect of Ubiquinone was investigated upon long-wavelength UV (UVA)-irradiated cultured human keratinocyte (HaCaT) cells and murine melanoma (B16F10) cells exposed to alpha-melanocyte stimulating hormone (α-MSH).[56] In preparation for UVA irradiation, HaCaT cells were pretreated with either 1 - 4 μM Ubiquinone in 0.1% propanol, or only 0.1% propanol, for 24 h. Cells were washed with phosphate-buffered saline (PBS), resuspended in Dulbecco's modified Eagle medium containing 10% fetal bovine serum, and then exposed to UVA radiation at doses of 5-15 J/cm^2, λ_{max} 365 nm, for 30 to 90 min. In contrast to an increase of ROS normally seen in UVA-exposed keratinocytes, Ubiquinone pretreatment was shown to suppress ROS-mediated α-MSH production, thus inhibiting melanogenesis, even in un-irradiated HaCaT cells. Concomitantly, B16F10 cells were pretreated with 1 - 2 μM of Ubiquinone, with or without exogenous α-MSH, for 2 h. The cells were then incubated for up to 72 h, washed twice with PBS, solubilized in 1 N sodium hydroxide, and analyzed for cell melanin content.[56] In spite of α-MSH -stimulation, Ubiquinone was shown to inhibit melanogenesis associated transcription factor expression.

Zebrafish embryos (9 h post-fertilization) were treated with 2 μM of Ubiquinone for 72 h and observed for depigmentation; a comparison was made with controls that were treated with 0.2 mmol/l 1-phenyl-2-thiourea or propanol.[56] Zebrafish body pigmentation remarkably decreased by 56% at 48 h and 66% at 72 h, when exposed to Ubiquinone.

Mouse melanoma (B16) cells were measured for melanin content and tyrosinase (a key enzyme for melanin synthesis) activity after treatment with 0.5, 1, or 2 μM Ubiquinone, or sodium ascorbate, for 72 h.[57] Ubiquinone treatment resulted in decreased melanin content in a dose-dependent manner, which corresponded to inhibited tyrosinase activity in treated cells. The authors noted that exposure to 2 μM Ubiquinone showed similar inhibitory effects as that of 0.5 mM ascorbic acid.

Cytotoxicity

Ubiquinone

In a melanin synthesis study, the cell lines were first tested for viability using a 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) colorimetric assay.[56] Murine melanoma B16F10 cells (1 x 10^5 cells/well in 24-well plates) were exposed to 1-2 μM Ubiquinone for 24 h. One ml of 0.5 mg/ml MTT in PBS were then added to each well and incubated at room temperature for 1 h. After incubation, equal volumes of 0.8 ml dimethyl sulfoxide were added to dissolve the MTT formazan crystals. Measurements were taken 24, 48, and 72 h after exposure, at a wavelength of 570 nm using an enzyme-linked immunosorbent assay microplate reader. Ubiquinone did not exhibit cytotoxic effects on B16F10 cells under these study conditions.

Miscellaneous Biological Effects

Ubiquinone

Mevalonic acid is the chemical precursor to both Ubiquinone and cholesterol, the latter of which requires HMGC reductase (HMGCR) to be formed.[24] Oral consumption of Ubiquinone is a contraindication to statin, cholesterol-lowering, or anticoagulant drugs, because it targets HMGCR inhibitors, and may have vitamin K-like procoagulant effects .[58,59] In a 4-wk, prospective placebo-controlled trial, no significant changes in blood-clotting factors, such as the international normalized ratio and prothrombin time, were observed in 24 patients taking warfarin and 100 mg Ubiquinone.[60] However, in a 16-wk longitudinal study, in which subjects took an unspecified amount of Ubiquinone and an average weekly dose of 33.5 mg warfarin, there was a statistically significant association between bleeding events and the concomitant intake of Ubiquinone and warfarin (OR 3.91, 95% CI: 2.09 - 7.3).[61] These discrepancies may be attributed to differences in test substances, higher dosing, risk in the elderly, and those at risk for cardiovascular disease and stroke.[16,59,62]

DERMAL IRRITATION AND SENSITIZATION STUDIES

Irritation

Human

Ubiquinone

A patch test was performed in 50 subjects, using an undiluted test substance containing 1% Ubiquinone, 5% tocopherol acetate, and 94% squalane.[63] Thirty of the subjects were healthy volunteers, 6 had eczema, and 14 had sensitive skin; subjects were aged 18-65, and none reported to have allergies. The test substance was applied in square test chambers (Haye's) to the back for 48 h (occlusion not specified). Sodium dodecyl sulfate (SDS; 1%) and water were used as positive and negative controls, respectively. Treatment sites were assessed for erythema, scaling and fissure formation using 5 point visual scores at 30 min and 24 h after patch removal. Average scores for all 3 evaluation criteria were 0.0 at both time points, and the 1% Ubiquinone formulation was deemed non-irritating.

Sensitization

Animal

Ubiquinone

Ubiquinone, of unknown purity, was tested in groups of 10 Crj:Hartley guinea pigs in a maximization test, in a manner similar to OECD TG 406.[63] During the induction phase, 1.25% Ubiquinone, in 0.5% aqueous methyl cellulose, was injected intradermally, while 6.3% Ubiquinone in petrolatum was dermally applied (number of applications and induction period not stated). During challenge, Ubiquinone was dermally applied at 6.3%, and readings were scored at 24 and 72 h. Physiological saline served as the negative control, while 0.1% 2,4-dintrochlorobenzene (DNCB) in 10% sodium dodecyl sulfate served as positive control; 5 animals were used per control group. No skin reactions were observed in the test and negative control groups at the 24 and 72 h readings. A few cases of very slight erythema were observed immediately after patch removal, but regressed within 24 h. Well-defined erythema was observed in all animals after challenge with DNCB. Hence, Ubiquinone at a concentration of 6.3% was not a skin irritant or sensitizer.

Human

Hydroxydecyl Ubiquinone

A cream containing 0.01% Hydroxydecyl Ubiquinone was tested in a human repeat insult patch test (HRIPT) in 107 subjects, 50 of which reported having sensitive skin.[64] The test material was applied, undiluted, using semi-occlusive patches to the upper back for 24 h, 3 times a week, for a total of 9 applications, made over a 3-wk induction period. The test sites were graded two times a week, 24 h after removal of test patches, and were scored on a 5-point scoring system, including: 0 for no visible skin reaction, ± for barely perceptible erythema, 1+ for mild erythema, 2+ for well-defined erythema, 3+ for erythema and edema, and 4+ for erythema and edema with vesiculation. After a 2-wk period, a 24-h challenge application was made to a previously untreated site in the same manner as in the induction applications, and reactions were scored at 24, 48, and 72 h. The only visible reactions included 5 subjects exhibiting barely perceptible erythema (±) once during induction. The researchers concluded that the test material did not demonstrate clinically significant dermal irritation or sensitization.

Ubiquinone

An HRIPT was performed in 50 subjects with a test substance containing 1% Ubiquinone, 5% tocopherol acetate, and 94% squalane.[63] Twenty-four of the subjects were healthy volunteers, 8 had eczema, and 18 had sensitive skin. The test substance was applied undiluted, under occlusion, in square test chambers (Haye's) to the back for a total of 9, 24-h applications, made over a 3-wk induction period. After a 2-wk period, chambers filled with the test article were applied to both the previously treated site and an untreated site to test for possible sensitization. Treatment sites were assessed for erythema, scaling and fissure formation using 5-point visual scores at 24 h (30 min after patch removal), 48 h, 72 h, and 96 h after patch application. Average scores for all 3 evaluation criteria were 0.0 at all time points for both previously treated and untreated sites, and the 1% Ubiquinone formulation was deemed non-irritating and non-sensitizing.

OCULAR IRRITATION STUDIES

No ocular irritation studies were found in the published literature, and unpublished data were not submitted.

CLINICAL STUDIES

Numerous studies have investigated the efficacy and safety of Hydroxydecyl Ubiquinone, Ubiquinol, and Ubiquinone use for the treatment of cardiovascular disease,[65] inflammation and aging,[66,67] diabetes,[68-70] cancer,[71] and muscular and neurogenerative diseases.[2,3,35,72,73] Among higher doses of Ubiquinone tested for the treatment of neurodegenerative diseases, 1200 mg Ubiquinone was established as safe and well tolerated in a 16-month trial of 80 patients with early Parkinson's disease.[4,72] Hydroxydecyl Ubiquinone and Ubiquinone are being studied for their use as novel therapeutic targets in carcinogenesis, owing to mevalonate pathway involvement in anti-proliferative effects and cell survival, respectively.[74,75]

Multiple studies have explored the hypotensive potential of Ubiquinone, with conflicting results.[76-82] Although study findings can vary, the hypotensive potential of Ubiquinone is generally attributed to its improvement of blood lipid profiles, and endothelial function, both of which affect cardiovascular health and hypertension.[83]

Ubiquinone

The safety and tolerability of 98% Ubiquinone was tested in groups of 11 healthy men and women (only 22 men in the highest dosage group) for 4 wk at doses of 0, 300, 600, and 900 mg/d in a double-blind, placebo-controlled trial.[84] The test substance was in capsule form, containing 150 mg Ubiquinone and several excipients. Placebo capsules contained only safflower oil. Each subject took 3 capsules twice a day, in the morning and evening after meals. A physical examination, hematological tests, serum chemistry examination, and urinalysis were performed before, after 4 wk of administration, and 2 wk after study completion. Symptoms of the common cold and gastrointestinal effects were observed in all dosage groups, with some vomiting (number unknown) in the 900 mg group. Differences in symptom frequency, hematology, blood biochemistry, and urinalysis were not dose-related or considered clinically significant, demonstrating the safety of Ubiquinone in healthy adults, at an intake of up to 900 mg/d.

Case Reports

A 47-yr-old woman had a cream containing 0.5 % Hydroxydecyl Ubiquinone applied as part of a facial treatment in a salon.[85] Within 24 h, she developed severe edematous and vesicular dermatitis of the face, ears, and neck. Lesions were treated with a 2-wk course of oral prednisone. Patch test readings with the North American Contact Dermatitis Group standard test series were taken on day 2 and day 3, and only showed a positive rating to the cream of (++) on day 2 and (+++) on day 4. Individual ingredients were then premixed with petrolatum at finished product concentration and patch-tested. Second- and fourth-day readings showed a (++) and (+++) reaction, respectively, to 0.5% Hydroxydecyl Ubiquinone. No reaction was observed in 20 control subjects tested with the same ingredient.

In response to a 2-d prior application of a cream containing 0.5% Hydroxydecyl Ubiquinone, a 43-yr-old woman developed an itchy eruption.[16] Topical applications of corticosteroid were used for 5 d to resolve the dermatitis. The patient had positive patch-test reactions to 0.5% Hydroxydecyl Ubiquinone and the cream. In a similar case report, a 50-yr-old woman showed an acute onset of symptoms, with heat and tightness, 4 h after application of a 0.5% Hydroxydecyl Ubiquinone cream, followed by erythema and periorbital swelling the next day.[16] Patch testing showed positive reaction to 0.5% Hydroxydecyl Ubiquinone.

A 38-yr-old woman presented with a red, itchy, burning, swollen face after the second application of a facial cream (amount not specified) containing 1% Hydroxydecyl Ubiquinone.[86] The patient had a history of guttate psoriasis, but no background of atopic eczema or contact allergy. Periorbital eruption and infraorbital edema were clinically diagnosed as allergic contact dermatitis, and were treated with 1% hydrocortisone ointment and aqueous cream BP, a hydrocarbon-based emollient emulsion, applied twice daily. The eruption resolved, with desquamation, over 4 weeks. A 2-d patch test was conducted with allergens found in the British Contact Dermatitis Society baseline series, cosmetic and facial series, fragrances, and the patient's own products. Positive reactions readings were observed on day 2, 4, and 7 with nickel sulfate 0.5% (++), propolis 10% (++), and the facial cream (+++). Further patch testing was done using the individual constituents of the product provided by the manufacturer. These constituents were applied for 2 d using IQ Ultra chambers and readings were taken at day 2, 4, and 7. A positive reaction to 1% Hydroxydecyl Ubiquinone in a vehicle (unknown) was observed at day 4 and day 7.

SUMMARY

The safety of Disodium Ubiquinone, Hydroxydecyl Ubiquinone, Ubiquinol, and Ubiquinone, as used in cosmetics, is reviewed in this safety assessment. These ingredients have been grouped together because they share a 2,5-cyclohexadiene-1,4-dione core, with various alkyl chain substituents at the 2-position of the cyclohexadiene, to comprise the salts or metabolites, thereof. These ingredients are all reported to function in cosmetics as antioxidants, and some are also reported to function as skin protectants, skin conditioning agents, and/or hair conditioning agents.

According to 2022 VCRP data, Ubiquinone has the highest reported use amongst these ingredients, in 221 cosmetic products, of which 208 are leave-on formulations. The results of the 2018 concentration of use survey conducted by the Council indicate that the maximum leave-on use concentration in this ingredient group is 0.05% Ubiquinone in body and hand products. No use concentrations were reported in industry surveys of Hydroxydecyl Ubiquinone and Ubiquinol, and, according to VCRP and industry data, Disodium Ubiquinone is not currently in use in cosmetic products.

Dermally applied Ubiquinone, in ethanol, was able to penetrate the stratum corneum of porcine skin, at approximately 20% in the epidermis and 2% in the dermis. A solution of 1% Ubiquinone, in olive oil, was found to reach concentrations of 8 µg/g after 2 h, and 15 µg/g after 4 h, when applied to live rat skin. In an HPLC analysis of the penetration of 2 formulations containing Ubiquinone in excised female mammary tissue, 90% of the Ubiquinone dissolved in a hydrophilic cream was shown to penetrate to the viable epidermis, compared to 60% penetration of Ubiquinone in a microemulsion formulation. The average T_{max} of orally ingested, solubilized, Ubiquinone being captured between 6 - 8 h (T_{max}), suggests slow absorption and limited bioavailability in the intestine. In pharmacokinetic studies, rat plasma levels for Hydroxydecyl Ubiquinone plateaued at 8 h and exhibited a half-life of 4.5 h, while dog plasma levels had a biphasic decline with half-lives of 2.2 and 15.4 h. In both species, elimination was almost complete in 48 h. The range of Ubiquinone half-life in Wistar rats administered up to 1200 mg/kg/d was 10.7 to 15.2 h. After a one-time intravenous injection of 10 mg/kg solubilized Ubiquinone, plasma Ubiquinol levels had increased in Wistar rats by 89%, within one day of injection.

Twenty-five healthy male subjects were assigned to receive single doses of 150 or 750 mg/d Hydroxydecyl Ubiquinone, or repeated doses of up to 2250 mg/d Hydroxydecyl Ubiquinone, for 14 d, after eating breakfast. A slightly higher proportion of free and conjugated metabolites were excreted in the 750 mg group. The half-life of Ubiquinol was estimated to be 48 h in 80 healthy subjects who received a single dose of 150 or 300 mg; the Ubiquinol $AUC_{(0-48h)}$ was 74.61 µgh/ml and 91.76 µgh/ml, for the 150 and 300 mg groups. Twenty healthy males were administered, either fasting or post-prandially, 60 mg lipid-soluble Ubiquinone capsules along with 200 ml of water. In the fasting group, the uptake rate was 0.018 ± 0.006 µg/ml/h, while in the post-prandial group the uptake rate was 0.026 ± 0.008 µg/ml/h. The $AUC_{(0-10h)}$ was determined to be 4.9 µg/ml/h, in a single dose study, in which 120 mg lipid-soluble Ubiquinone was administered to 10 healthy subjects. In a pharmacokinetic study, a single, oral dose of 100 mg deuterium-labelled Ubiquinone was administered to 16 healthy male subjects and exhibited an elimination half-life of 33.19 ± 5.32 h.

The acute oral LD_{50} of Hydroxydecyl Ubiquinone was determined to be > 10,000 mg/kg in mice and male rats, and ~ 10,000 mg/kg in female rats. The acute oral LD_{50} of Ubiquinone was reported to be > 4000 mg/kg and > 20,000 mg/kg in mice, while the highest LD_{50} value was determined to be > 5000 mg/kg in rats.

Wistar rats orally administered up to 500 mg/kg/d Hydroxydecyl Ubiquinone for 4 wk exhibited a dose-dependent increase in the incidence and severity of forestomach mucosal inflammation, erosions, ulcerations, and hyperkeratosis. In another study, juvenile rats dosed at up to 1000 mg/kg/d Hydroxydecyl Ubiquinone for 4 wk, exhibited slight reduction of body weight in the mid- and high-dose groups, as well as an increased incidence and severity of hyaline droplet accumulation in the renal tubules, and reversible lowered bone density; the NOAEL was determined to be 200 mg/kg/d. The non-toxic oral dose of Hydroxydecyl Ubiquinone was determined to be 500 mg/kg/d in rats administered an unspecified dose over 5 wk, and 100 mg/kg/d in Beagle dogs, administered with up to 500 mg/kg/d over 5 wk. The highest non-toxic, oral Hydroxydecyl Ubiquinone doses were determined to be 500 mg/kg/d and 20 mg/kg/d, in a 5-wk, and a 26-wk study of rats, respectively. Gastric irritation, forestomach histopathology, and a general reduction of weight was observed in CD-1 mice administered 2000 mg/kg/d Hydroxydecyl Ubiquinone for 13 wk. In a 26-wk study of Wistar rats administered up to 1000 mg/kg/d Hydroxydecyl Ubiquinone, mucosal thickening, hyperkeratosis, red spots, hyperplasia, necrosis, edema, and ulceration observed in the forestomach were reversible and of limited toxicological relevance. Beagle dogs administered 500, 750, or 1000 mg/kg/d Hydroxydecyl Ubiquinone for 39 wk exhibited gastrointestinal disturbances and reduced heart rate across all groups, as well as mild liver hypertrophy and pulmonary hyperplasia in a few animals in the 1000 mg group. These results were not considered statistically significant.

Groups of 10 Sprague-Dawley rats were dosed at up to 1200 mg/kg/d Ubiquinol for 13 wk. Fine vacuolation of the hepatic Kupffer cells and statistically significant increases in hepatic blood chemistry enzymes, were observed in rats dosed with ≥ 300 mg/kg Ubiquinol. No deaths or adverse clinical effects were observed, and the NOAELs were conservatively estimated to be 600 mg/kg/d in male rats, and 200 mg/kg/d in female rats. In a follow-up study, groups of 10 female Sprague-Dawley rats were dosed at up to 1200 mg/kg/d, and no toxicologically significant changes related to the test material were observed. Groups of 3 Beagle dogs were dosed at up to 600 mg/kg/d Ubiquinol for 13 wk. Soft feces were observed in the 300 and 600 mg/kg/d Ubiquinol groups, and estrus hemorrhage in 1 female each in the control and 300 mg Ubiquinol groups. The NOAEL for Ubiquinol was determined to be 600 mg/kg/d in Beagle dogs.

No noticeable changes in overall condition, body weight gain, or food consumption, were seen in cRj Wistar rats, in comparison to controls, during 4-wk oral treatment with 1000 mg/kg/d Ubiquinone. Upon necropsy, a few abnormalities were observed in the adrenals and lungs of several treated male and female rats in the Ubiquinone-treated group. No mortality or toxicity occurred in rats dosed at up to 2250 mg/kg/d Ubiquinone. Groups of 15 Sprague-Dawley rats which were dosed at up to 3000 mg/kg/d over 90 d exhibited statistically significant changes in hematological markers and ovary weights in the two highest dosage groups. Groups of 10 Sprague-Dawley rats dosed with 1200 mg/kg/d Ubiquinone for 13 wk, showed a statistically significant higher food consumption in females, mild granuloma of the liver in females, as well as yellow lung foci and accumulation of foam cells in lung alveoli in 2 males and 3 females. The NOAEL was determined to be ≥ 1200 mg/kg/d in another 13-wk study of Sprague-Dawley rats. In a 52-wk study, one female and three male Sprague-Dawley rats died from the 600 mg/kg/d group, and one male from the 1200 mg/kg/d group died of malignant lymphoma. No toxic effects and microscopic, or gross, pathologies were found in white rabbits dosed for 23 d with up to 600 mg/kg Ubiquinone. Groups of 3 Beagle dogs dosed with 600 mg/kg/d Ubiquinone for 13 wk, exhibited soft feces with traces of test article, vomiting, and a statistically significant increase in neutrophils. A dark red focus of the heart was observed in 1 male, while 1 male and 1 female exhibited enlarged livers; opacity of the posterior lens capsule in 1 Ubiquinone-treated female was observed, which also occurred in control group animals. No deaths occurred during the treatment of Beagle dogs dosed at up to 1800 mg/kg/d for 39 wk, and gross pathological findings were not considered toxicologically significant.

No adverse effects on fertility or reproductive performance were observed in a study in which male and female Wistar rats were dosed orally with up to 500 mg/kg bw Hydroxydecyl Ubiquinone prior to mating, during gestation, and until day 22 post-partum. No statistically significant adverse effects upon reproductive performance or fetal development were seen in several studies of rats dosed at up to 1000 mg/kg/d Hydroxydecyl Ubiquinone, although a higher incidence of post-partum implantation loss was reported. The NOAELs for embryofetal development, and male and female fertility were determined to be 1000 mg/kg/d, 500 mg/kg/d, and 1000 mg/kg/d, respectively. The offspring of rabbits dosed with up to 150 mg/kg/d Hydroxydecyl Ubiquinone displayed chromaturia in the highest dosage group. In rabbits dosed at up to 500 mg/kg/d Hydroxydecyl Ubiquinone, one abortion was observed in the highest dosage group, but was considered spontaneous, and not significant. In peri/post-natal studies of rats, no treatment-related changes were observed in dams, and the NOAEL for pup development was determined to be 500 mg/kg/d Hydroxydecyl Ubiquinone. No effect on fetal death, weight, or postnatal toxicity was observed in primigravid mice dosed with up to 600 mg/kg/d Ubiquinone, from day 7 to day 13 of gestation. No statistically significant differences were found in the incidence of sperm abnormalities in male mice dosed with up to 10,000 mg/kg bw Ubiquinone for 5 d, via gavage, and were assessed after a 35-d observation period, compared to corn-oil-treated controls. Except for an increase in seminiferous epithelium heights, no biochemical, histological, or morphological differences were observed between 8 male Wistar rats dosed at 10 mg/kg bw/d Ubiquinone for 14 d, and negative control and vehicle control groups. Treatment with Ubiquinone had no effect on fetal death, weight, or postnatal activity in primigravid rats dosed at up to 600 mg/kg/d, from day 9 to day 15 of gestation.

Hydroxydecyl Ubiquinone exhibited a positive mutagenic response in a mutation induction test with L5178Y TK +/- mouse lymphoma cells and a chromosomal aberration test with human peripheral lymphocytes; however, these results were attributed to the redox properties of the test substance and were not considered significant. Ubiquinol and Ubiquinone were not genotoxic, with or without metabolic activation, in multiple Ames test or chromosomal aberration tests at up to 5000 µg/plate. No genotoxicity was observed in several in vivo micronucleus tests, with Hydroxydecyl Ubiquinone, at up to 5000 mg/kg/d in mice, Ubiquinol, at up to 2000 mg/kg/d in Sprague-Dawley rats, or Ubiquinone, at up to 10,000 mg/kg/d, in mice.

ICR mice fed a daily dose of up to 2000 mg/kg Hydroxydecyl Ubiquinone via diet for 103 wk, exhibited a low incidence of benign tumors in the mid- and high-dose groups; the incidence was within the expected range for this mouse strain. Adverse forestomach effects and the incidence of various malignancies were observed in Sprague-Dawley rats fed a daily dose of up to 1000 mg/kg Hydroxydecyl Ubiquinone via diet for 104 wk. The incidence of these neoplasms was lower than expected for this strain, and only in males.

Vitiligo-susceptible individuals experienced depigmentation when exposed to skin preparations containing oxidized Ubiquinone, ostensibly due to the bleaching effects of an oxidation byproduct, hydrogen peroxide. Ubiquinone was shown to inhibit melanogenesis in UVA-irradiated HaCaT and B16F10 cells stimulated with α-MSH. Zebrafish embryos treated with 2 µM of Ubiquinone post-fertilization for 72 h exhibited up to a 66% reduction in body pigmentation, compared to controls treated with 0.1% propanol. Decreased melanin content in B16 cells treated with up to 2 µM Ubiquinone for 72 h corresponded with inhibited tyrosinase activity. In a melanin synthesis study, B16F10 cells were tested for viability in an MTT assay. Cytotoxic effects were not observed after 24 h exposure to 1 - 2 µM Ubiquinone.

Clinically, Hydroxydecyl Ubiquinone, Ubiquinol, and Ubiquinone have been tested for safety and efficacy in the treatment of various diseases at doses up to 1200 mg. The safety and tolerability of 98% Ubiquinone was tested in groups of 11 healthy men and women (only 22 men in the highest dosage group) for 4 wk at doses of 0, 300, 600, and 900 mg/d in a double-blind, placebo-controlled trial. Symptoms of the common cold and gastrointestinal effects were observed in all dosage groups, with some vomiting (number unknown) in the 900 mg group. Differences in symptom frequency, hematology, blood biochemistry, and urinalysis were not dose-related or considered clinically significant; Ubiquinone intake was deemed safe at doses of up to 900 mg/d in healthy adults.

A 48 - h patch test was performed (occlusion not specified) in 50 subjects, using an undiluted test substance containing 1% Ubiquinone, 5% tocopherol acetate, and 94% squalene. After patch removal, test sites were evaluated for erythema, scaling, and fissure formation at 30 min and 24 h after patch removal. Average scores were 0.0 at all time points for all 3 evaluation criteria, and the 1% Ubiquinone formulation was deemed non-irritating. In a guinea pig maximization test, a test material containing 1.25% Ubiquinone in 0.5 % aqueous methyl cellulose was injected intradermally, and 6.3% Ubiquinone in petrolatum was applied dermally, during induction, to groups of 10 Crj:Hartley guinea pigs. During challenge, 6.3% Ubiquinone was dermally applied, and readings were scored at 24 and 72 h. Slight erythema, occurring immediately after patch removal, regressed within 24 h; 6.3% Ubiquinone was not a skin irritant or sensitizer. A cream containing 0.01% Hydroxydecyl Ubiquinone was tested neat in a semi-occlusive HRIPT completed in 107 subjects, 50 of which reported having sensitive skin. The researchers determined that the test material did not demonstrate clinically significant dermal irritation or sensitization. An occlusive HRIPT of a test substance containing 1% Ubiquinone, applied neat, was performed in 50 subjects, of which 18 reported having sensitive skin. Average scores were 0.0 for all 3 evaluation criteria and the 1% Ubiquinone formulation was deemed non-irritating and non-sensitizing.

Four women presented with facial eruptions and sensitization reactions in response to application of creams containing up to 1% Hydroxydecyl Ubiquinone. Positive patch-test reactions occurred for 0.5% and 1.0% Hydroxydecyl Ubiquinone.

DISCUSSION

This assessment reviews the safety of 4 Ubiquinone ingredients as used in cosmetic formulations. The Panel concluded that these 4 Ubiquinone ingredients are safe in the present practices of use and concentrations described in this safety assessment.

The Panel noted that Hydroxydecyl Ubiquinone is a synthetic analog of Ubiquinone with a shorter chain structure, it could reasonably be grouped with the other ingredients because of its shared bioactive ring structure. The Panel also discussed that the inefficiency and expense of extracting these ingredients from biological tissues would most likely make either chemical synthesis, or, microbial fermentation, the primary means of production. In the absence of method of manufacture, impurities, and concentration of use data for Hydroxydecyl Ubiquinone and Ubiquinol, the Panel's safety concerns were mitigated due to the natural occurrence of Ubiquinone in living tissues, use as a food additive and nutritional supplement, as well as the abundance of negative results for developmental and genetic toxicity, and sensitization.

Data included in this report indicate that Ubiquinone may have a skin lightening effect. The Panel noted that skin lightening is considered to be a drug effect and should not occur during the use of cosmetic products. Because of that caveat, and based on the low concentrations of use of these ingredients in cosmetic products, the Panel's knowledge of the mechanism of action (i.e., inhibition of tyrosinase activity resulting in reduced melanin synthesis), the results of the in vitro studies of Ubiquinone, and clinical experience, concern for this effect in cosmetics was mitigated. Nevertheless, cosmetic formulators should only use these Ubiquinone ingredients in products in a manner that does not cause depigmentation.

CONCLUSION

The Expert Panel for Cosmetic Ingredient Safety concluded that the following 4 Ubiquinone ingredients are safe in cosmetics in the present practices of use and concentrations described in the safety assessment:

Disodium Ubiquinone*
Hydroxydecyl Ubiquinone**
Ubiquinol**
Ubiquinone

*Not reported to be in current use. Were this ingredient not in current use to be used in the future, the expectation is that it would be used in product categories and at concentrations comparable to others in this group.

**Concentrations of use not reported. The expectation is that these ingredients would be used in product categories and at concentrations comparable to the other ingredients.

TABLES

Table 1. Definitions, reported cosmetic functions, and chemical structures of ingredients in this report[1,CIR Staff]

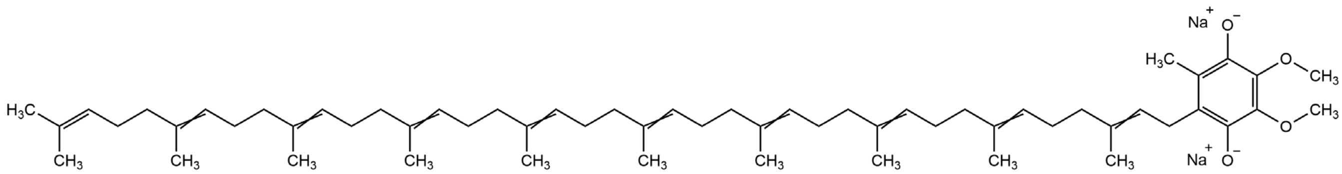
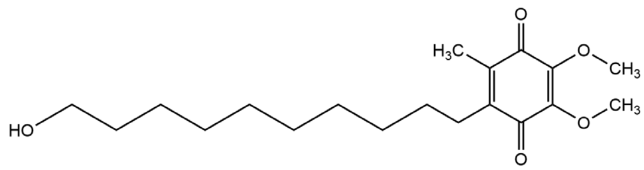
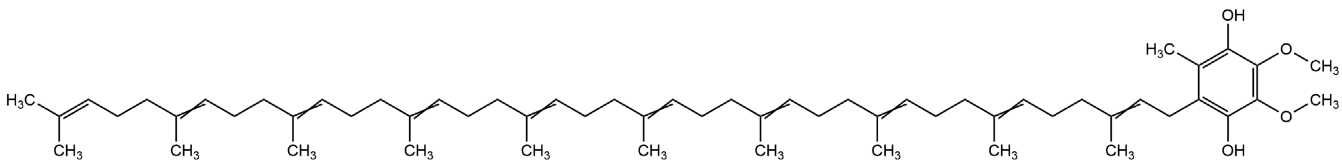
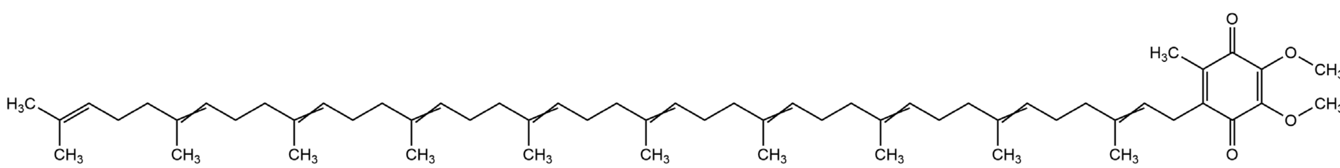
Ingredient (CAS No.)	Definition	Function(s)
Disodium Ubiquinone	Disodium Ubiquinone is the disodium salt of Ubiquinone.	Antioxidants; Hair Conditioning Agents; Skin Protectants; Skin-Conditioning Agents-Humectant
		
Hydroxydecyl Ubiquinone	Hydroxydecyl Ubiquinone is the organic compound that conforms to the structure: 	Antioxidants
Ubiquinol (992-78-9)	Ubiquinol is the organic compound that conforms to the structure:	Antioxidants, Skin Protectants; Skin-Conditioning Agents- Humectant
		
Ubiquinone (303-98-0; 60684-33-5)	Ubiquinone is the organic compound that conforms to the structure:	Antioxidants; Skin-Conditioning Agents-Miscellaneous
		

Table 2. Chemical properties

Property	Value	Reference
	Disodium Ubiquinone	
Formula Weight (g/mol)	865.38	87
Partition coefficient (log K_{ow})	20.23 (estimated)	6
	Hydroxydecyl Ubiquinone	
Physical Form	Solid	35
Molecular Weight (g/mol)	338.4	88
Topological Polar Surface Area (Å^2)	72.8 (estimated)	88
Melting Point (ºC)	52-54	35
Partition coefficient (log K_{ow})	3.88 (estimated)	6
	Ubiquinol	
Molecular Weight (g/mol)	865.4	7
Topological Surface Area (Å^2)	58.9 (estimated)	7
Partition coefficient (log K_{ow})	23.74 (estimated)	6
Water Solubility	Sparingly	7
	Ubiquinone	
Physical Form	Solid, crystalline powder	8
Color	Off-white to yellow-orange	21,58
Molecular Weight (g/mol)	863.3	8
Topological Surface Area (Å^2)	52.6 (estimated)	8
Melting Point (ºC)	50-52	8
Partition coefficient (log K_{ow})	16.51 (estimated)	6
Water Solubility (@ 20.5 ºC)	Sparingly	8

Table 3. Frequency (2022) and concentration of use (2018) according to the duration and type of exposure for Ubiquinone ingredients

	# of Uses[30]	*Max Conc of Use (%)*[31]	*# of Uses*[30]	*Max Conc of Use (%)*[32]	*# of Uses*[30]	*Max Conc of Use (%)*[31]
	Hydroxydecyl Ubiquinone		**Ubiquinol**		**Ubiquinone**	
Totals*	**16**	**NR**	**6**	**NR**	**221**	**0.00006-0.05**
Duration of Use						
Leave-On	*15*	*NR*	*6*	*NR*	*208*	*0.00075-0.05*
Rinse-Off	*1*	*NR*	*NR*	*NR*	13	*0.000006-0.03*
Diluted for (Bath) Use	*0*	*NR*	*NR*	*NR*	*NR*	*NR*
Exposure Type						
Eye Area	NR	NR	NR	NR	11	0.02
Incidental Ingestion	NR	NR	NR	NR	1	NR
Incidental Inhalation-Spray	6[a]; 6[b]	NR	2[a]; 4[b]	NR	142[a]; 39[b]	0.00075 – 0.01[a]
Incidental Inhalation-Powder	6[b]	NR	4[b]	NR	39[b]	0.05[c]
Dermal Contact	16	NR	6	NR	218	0.00075-0.05
Deodorant (underarm)	NR	NR	NR	NR	NR	NR
Hair - Non-Coloring	NR	NR	NR	NR	2	0.000006-0.01
Hair-Coloring	NR	NR	NR	NR	NR	NR
Nail	NR	NR	NR	NR	NR	NR
Mucous Membrane	NR	NR	NR	NR	2	NR
Baby Products	NR	NR	NR	NR	NR	NR

*Because each ingredient may be used in cosmetics with multiple exposure types, the sum of all exposure types may not equal the sum of total uses.
[a] It is possible these products are sprays, but it is not specified whether the reported uses are sprays.
[b] Not specified whether a spray or a powder, but it is possible the use can be as a spray or a powder, therefore the information is captured in both categories
[c] It is possible these products are powders, but it is not specified whether the reported uses are powders
NR – not reported

Table 4. Acute oral toxicity studies

Ingredient	Species	No./Group	Vehicle	Dose/Protocol	LD_{50}/Results	Reference
Hydroxydecyl Ubiquinone	Mice	NR	NR	NR	>10,000 mg/kg for male and female mice. Besides decreased locomotor activity in mice with the highest exposure, no statistically significant changes were noted in treated animals.	49,50
Hydroxydecyl Ubiquinone	Rats	NR	NR	NR	>10,000 mg/kg for male rats ~10,000 mg/kg for female rats Besides decreased locomotor activity in high dosed rats, no statistically significant changes were noted in treated animals.	49,50
Ubiquinone	Mice	NR	NR	NR	>4000 mg/kg. No death or toxic symptoms were observed during the one-week observation period.	34
Ubiquinone, >98% purity	ICR mice	10/sex	Composition not specified	20,000 mg/kg bw via gavage	>20,000 mg/kg; No clinical signs, adverse effects, or mortality was observed.	51
Ubiquinone	cRj Wistar rats	3/sex/dose	Corn oil	2000 mg/kg via gavage	>2,000 mg/kg. No deaths and pathological changes in organs or tissues was observed.	21
Ubiquinone	Rats	NR	NR	NR	>4000 mg/kg. No death or toxic symptoms were observed during the one-week observation period.	34
Ubiquinone	Rats	NR	Corn oil	1250, 2500, or 5000 mg/kg	>5,000 mg/kg	34

NR-not reported

Table 5. Repeated dose oral toxicity studies

Ingredient	Animals or Subjects/Group	Study Duration	Vehicle	Dose/Concentration/Protocol	Results	Reference
Hydroxydecyl Ubiquinone	Wistar rats (# not specified)	4 wk	NR	20, 100, 500 mg/kg/d, via gavage	Local effects in the forestomach mucosa were observed (details on which dosage group not provided), such as yellow coloration, mucosal thickening, occasional dilation and appearance of red spots. Dose-dependent increases included incidence/severity of submucosal inflammatory infiltrates, forestomach erosions and ulcerations, hyperkeratosis, epithelial and basal cell hyperplasia, focal necrosis, and edema (statistical significance not provided).	[2]
Hydroxydecyl Ubiquinone	juvenile Wistar rats (# not specified)	4 wk	NR	Up to 1000 mg/kg/d (further details not provided)	A slight reduction of body weight was observed in the mid- and high-dose groups, as well as an increased incidence and severity of hyaline droplet accumulation in the proximal renal tubules of male rats in the 1000 mg dosage group. Lowered bone density in the femur and lumbar vertebrae of females in the high dose group were reduced with recovery. No effects on development or reproductive function were observed (statistical significance not provided). The NOAEL was determined to be 200 mg/kg/d.	[3]
Hydroxydecyl Ubiquinone	Rats (strain and # not specified)	5 wk	NR	doses not stated; administered orally, with a 5-wk recovery period	Toxic effects observed at a dose of 2500 mg/kg/d proved reversible within the recovery period. The non-toxic oral dose was determined to be 500 mg/kg/d (statistical significance not provided).	[49]
Hydroxydecyl Ubiquinone	Beagle dogs (# not specified)	5 wk	NR	Up to 500 mg/kg/d; administered orally	Diarrhea and soft feces were observed in both sexes at a dose of 500 mg/kg/d, and in males dosed with 100 mg/kg/d. The non-toxic oral dose was determined to be 100 mg/kg/d (statistical significance not provided)	[49]
Hydroxydecyl Ubiquinone	CD-1 mice (# not specified)	13 wk	NR	210, 640, 1280, 2000 mg/kg/d, administered orally	Gastric irritation, mainly in the form of epithelial cell hyperplasia, histopathological abnormalities in the forestomach, and a general reduction of weight was observed. (Further details not provided).	[3]
Hydroxydecyl Ubiquinone	Rats (strain and # not specified)	26 wk	NR	doses not stated; administered orally	Although no treatment-related changes were observed at necropsy, a dose of 500 mg/kg/d caused pathological changes in the gastric mucosa. The non-toxic dose was determined to be 20 mg/kg/d (statistical significance not provided)	[49]
Hydroxydecyl Ubiquinone	Wistar rats (# not specified)	26 wk	NR	30, 100, 300, 1000 mg/kg/d, via gavage	Mucosal thickening, hyperkeratosis, red spots, hyperplasia, necrosis, edema, and ulceration were observed in the forestomach of the animals (groups not specified) upon necropsy. Similar effects were seen in the glandular stomach, including red spots, hyperplasia, and ulceration. These effects were reversible, considered rodent-specific, and of limited toxicological relevance.	[3]
Hydroxydecyl Ubiquinone	Beagle dogs (# not specified)	39 wk	NR	0, 500, 750, 1000 mg/kg/d, via gavage; with an 8-wk recovery period	A dose-dependent incidence of vomiting of mucus, yellow/orange fluid and/or feed, loose feces, diarrhea, body weight loss, and lower food consumption was observed. (doses not specified). The incidence and severity of these clinical signs were greatest in animals dosed at 1000 mg/kg/day and all reported changes were reversible. A non-dose-dependent decrease in mean heart rate was recorded in all groups (occasionally prior to dosing) at wk 26 and wk 39 especially in male dogs, when compared to controls. These cardiac symptoms were associated with lower activity, food consumption, weight loss, and were not observed in 8 wk recovery group. Two animals in the 1000 mg dose group showed mild liver hypertrophy, without further indication of hepatic injury, and 2 additional animals in this dosing group exhibited lung fibrosis, edema, inflammation, and alveolo-bronchiolar hyperplasia. (statistical significance not provided).	[2,3]

Table 5. Repeated dose oral toxicity studies

Ingredient	Animals or Subjects/Group	Study Duration	Vehicle	Dose/Concentration/Protocol	Results	Reference
Ubiquinol	Sprague-Dawley rats (10/sex)	13 wk	Corn oil	0, 300, 600, or 1200 mg/kg/d, via gavage 1200 mg/kg/d Ubiquinone was used as a reference control group (see Ubiquinone studies for results).	No deaths, or adverse clinical effects, were observed during treatment. A statistically significant higher food consumption was observed in the both males and females in the 600 mg/kg/d group, on day 91 and 31 of dosing, respectively. Elevated AST, ALT, and LDH activity was seen in females in the ≥300 mg/kg groups. Significantly lower A/G ratios were seen in 300 and 1200 mg/kg females; as well as a higher value in the proportion of β-globulin in the protein fractions of females in the 1200 mg/kg group, and γ-globulin in males in the 300 mg/kg group. Statistically significant prolongations in APTT and PT were observed in 1200 mg/kg males, but were within in-house historical control data. Histopathological examinations revealed test-article related effects in the spleen, mesenteric lymph, and within the liver of females only. A yellow focus in the lung was observed in 1 female each in the 300, 600, and 1200 mg/kg groups. Fine vacuolation of Kupffer cells in the liver was present in multiple females dosed with ≥300 mg/kg. The NOAEL was conservatively estimated to be 600 mg/kg/d for males and 200 mg/kg/d for female rats.	29
Ubiquinol	Sprague-Dawley rats (10, only females)	13 wk	Corn oil	0, 75, 150, 200, 300, 1200 mg/kg/d, via gavage; this study served as a follow-up trial to the study listed above. Reference control group received 1200 mg/kg/d Ubiquinone	No deaths or significant changes related to the test material were observed. There were no abnormal ophthalmic findings. Food consumption was not affected. Histopathological examinations revealed fine vacuolation in hepatocytes in 3 females in the 200 mg/kg Ubiquinol group, 4 females in the 300 mg/kg Ubiquinol groups, and 3 females in the Ubiquinone group. Mild accumulation of macrophages was also observed in the spleen of 1 female in the 300 mg/kg Ubiquinol group, and in 3 females each in the 300 mg/kg Ubiquinol and Ubiquinone groups. A mild accumulation of foam cells and slight infiltration in the alveoli was seen in 1 female each in the 300 mg/kg Ubiquinol and Ubiquinone groups. (statistical significance not provided). Yellow focus of the lung was observed in 1 female in the 150 mg/kg Ubiquinol group, and 2 females each in the 300 mg/kg Ubiquinol group and Ubiquinone groups. Statistically significant changes in AST activity were observed within animals in the 300 mg/kg group, suggesting effects on the liver. However, these changes were not dose-related, and were observed in controls.	29
Ubiquinol	Beagle dogs (3/sex)	13 wk	Gelatin capsules; corn oil for the negative control group	0, 150, 300, or 600 mg/kg/d, via gavage 600 mg/kg/d Ubiquinone was used as a reference control group (see Ubiquinone studies for results).	Minimal Ubiquinol-related effects were observed in body weight, food consumption, ophthalmology, electrocardiogram, urinalysis, hematology, blood chemistry, or histopathological examination. Soft or mucous feces, containing test article or control-like material, were observed during treatment in 1 male in the 150 mg/kg group, 2 males and 1 female in the 300 mg/kg group, and in all males and females in the 600 mg/kg group. Vomiting of foamy fluid was observed in all dosage groups, and vomit containing test article-like material was observed sporadically in the 300 and 600 mg/kg dosage groups; however, vomiting was also observed in controls and was considered unrelated to treatment. Yellow discoloration of the liver was observed in 1 male in the 600 mg/kg group, and a dark red focus was observed in the duodenum of 1 female in the 150 mg/kg group. Estrus hemorrhage was observed in 1 female in the control and 1 female in the 300 mg/kg Ubiquinol group. Statistically significant higher AST, ALT, and LDH values were observed in females in the 300 mg/kg group during wk 13 of dosing, and low A/G ratios were observed in males in the 600 mg/kg group in wk 7 and 13 of dosing, but these effects were judged to be incidental. A statistically significant low proportion of eosinophils was observed in males in the 150 and 600 mg/kg group, as was a low platelet count in females in the 300 mg/kg group; however, these values were not considered test article related and were within testing facility ranges. Yellow discoloration of the liver was observed in 1 male in the 600 mg/kg group. A NOAEL of 600 mg/kg/d was determined.	29
Ubiquinone	White rabbits (# not specified)	23 d	NR	0, 6, 60, 600 mg/kg/d; administered orally	No toxic effects, and no microscopic or gross lesions, were found at any dose level. (statistical significance not provided).	34

Table 5. Repeated dose oral toxicity studies

Ingredient	Animals or Subjects/Group	Study Duration	Vehicle	Dose/Concentration/Protocol	Results	Reference
Ubiquinone	cRj Wistar rats (6/sex)	4 wk	Corn oil	1000 mg/kg/d, via gavage; general toxic signs, food consumption, body and organ weights, hematology and urinalysis, and gross and micropathological changes were observed	Ubiquinone did not produce notable changes in the overall condition, body weight gain, or food consumption, of the test animals when compared with controls. Upon necropsy in the Ubiquinone-treated group, one male had enlarged adrenals, and one male had tan-colored lungs, which was attributed to administration errors. One female from the control group, and several males and females from the Ubiquinone-treated group, exhibited hemorrhagic lesions, and localized pulmonary changes. (statistical significance not provided).	21
Ubiquinone, >98% purity	Sprague-Dawley rats (10/sex)	30 d	Composition not specified; corn oil for controls	0, 560, 1130, 2250 mg/kg/d, via gavage; body and relative organ weights, food intake, and blood biochemistry were observed	No difference in the body weight, food intake, organ weights, or blood biochemistry of the treated animals compared to controls was observed.	51
Ubiquinone	Rats (strain and # not specified)	5 wk	NR	0, 40, 200, 1000 mg/kg/d; administered orally	No toxicity was observed in the hematology, blood chemistry, urinalysis, or post-mortem examinations at any dose level.	34
Ubiquinone, 99.8% purity	Sprague-Dawley rats (15/sex); 1/3 of the rats were used as a 15-d recovery group before sacrifice	90 d	0.5% hydromethyl-fibrin	0, 500, 1500, 3000 mg/kg/d, via gavage; 5/sex/group were maintained after the termination of dosing, and served as recovery group animals	Male rat body weights decreased during treatment in the 1500 mg/kg group. In female rats, food consumption was reduced in the 3000 mg/kg group in week 1, week 3, and week 7. Red blood cells and hemoglobin decreased in the 500 mg/kg and 1500 mg/kg male dosage group, while white blood cells increased in all males for all dosages. Hematocrit levels in the 1500 mg/kg and 3000 mg/kg female groups were also decreased. Triglycerides decreased in the 1500 mg/kg and 3000 mg/kg male dosage groups. Ovary weight was slightly decreased in the 1500 mg/kg group, while uterus-to-body weight ratio was elevated in the 3000 mg/kg dosage group. All these changes were statistically significant. No significant differences or toxic effects were observed in the recovery group.	14
Ubiquinone	Sprague-Dawley rats (10/sex)	13 wk	Corn oil	1200 mg/kg/d, via gavage (Reference controls for the 13-wk Ubiquinol study)	A statistically significant higher food consumption was observed in females on day 4 and 31 of dosing. Statistically significant prolongations in PT were observed in 1200 mg/kg males, but were within in-house historical control data. Two males and 3 females exhibited a yellow focus in the lung. Mild granuloma was present in the livers of females, as well as an accumulation of foam cells in lung alveoli in 2 males and 3 females. (statistical significance not provided).	29
Ubiquinone	Sprague-Dawley rats (10/sex)	13 wk	Corn oil	0, 300, 600, 1200 mg/kg/d, via gavage; clinical observations, body and organ weights, food consumption, blood chemistry, and histopathology were observed	No deaths or changes in food consumption occurred during treatment. The test substance was excreted in the stool of rats in the 1200 mg/kg group. Other incidental observations among rats in the 1200 mg/kg group included mononuclear cell infiltration in the pancreas, mineralization in the kidney medulla and duct of the parotid gland, lymphocyte infiltration in the submucosa of the bladder, and cysts in the parathyroid of rats in the 1200 mg/kg group. These changes were considered to be unrelated to the test substance as they are known to occur spontaneously. (statistical significance not provided). The NOAEL was determined to be > 1200 mg/kg/d.	17
Ubiquinone	Beagle dogs (3/sex)	13 wk	Corn oil	600 mg/kg/d, via gavage (Reference controls for the 13-wk Ubiquinol study)	Soft feces, with apparent traces of Ubiquinone, were observed during treatment in 2 males and 2 females. Soft, mucous, or watery feces were also observed 10 times in 1 reference control male and 1 time in a female from the control group. Vomiting was also observed in 1 male and 2 females during dosing. Estrus hemorrhage was observed in 1 female from wk 9 to 11 of dosing. A statistically significant increase in proportion of band neutrophils was observed in Ubiquinone-treated males at wk 7, but was not detected at wk 13. A dark red focus of the heart was observed in 1 male; 1 male and 1 female exhibited an enlarged liver. Opacity of the posterior lens capsule was observed in 1 of the 3 females, but also occurred in 1 male and 2 females in the control group. (statistical significance not provided).	29

Table 5. Repeated dose oral toxicity studies

Ingredient	Animals or Subjects/Group	Study Duration	Vehicle	Dose/Concentration/Protocol	Results	Reference
Ubiquinone	Beagle dogs (4/sex)	39 wk	Gelatin capsules	0, 1200, or 1800 mg/kg/d; administered orally, via gelatin capsules	Unabsorbed Ubiquinone was observed in the stool of all male and females who received 1200 or 1800 mg/kg/d. Vomiting occurred in one male and 3 females in the 1200 mg/kg/d group and in all dogs in the 1800 mg/kg/d group. No deaths were observed during treatment. Upon necropsy, a white focus was observed in the lungs of one control female and one male from the 1200 mg/kg/d group. One male in the control group was found to have hypoplasia of the epididymis. These gross pathological findings were not considered toxicologically significant.	52
Ubiquinone	Sprague-Dawley rats (19/sex)	52 wk	Corn oil, via gavage	0, 100, 300, 600, or 1200 mg/kg/d, via gavage; 10 animals of random sex were selected from the 0, 600, and 1200 mg/kg/d dosage groups. These 3 groups of recovery animals were treated for 52 wk, and maintained after the termination of dosing for 4 wk,	One female and three males from the 600 mg/kg/d group died during weeks 33, 38, 48, and 52. One male from the 1200 mg/kg/d group died of malignant lymphoma during week 33. No statistically significant differences were observed in body weight, ophthalmology, or clinical and anatomical pathology. Increased incidence of large, finely vacuolated (foamy) macrophages in the lymph nodes and hepatic periportal cells, attributed to phagocytic activity, were observed in the 600 and 1200 mg/kg/d groups. Although Ubiquinone accumulated in the liver, in recovery groups, levels returned to pretreatment levels within 10 d of stopping treatment. During treatment, red nasal discharge was observed in one female control, and in both sexes in the mid and high dose groups. Orange material was found in the feces during treatment and upon necropsy, was found in the lungs and in the nasal turbinates, which was attributed to external incidental exposure to crystallized Ubiquinone.	44

Abbreviations: A/G – albumin/globulin; APTT – activated partial thromboplastin time; ALT- alanine aminotransferase; AST – aspartate aminotransferase; LDH – lactate dehydrogenase; NR- not reported; PT – prothrombin time

Table 6. Developmental and reproductive toxicity studies

Test Article	Animals/Group	Vehicle	Dose/Concentration	Procedure	Results	Reference
				ORAL		
Hydroxydecyl Ubiquinone	Wistar rats (# not specified)	NR	20, 100, or 500 mg/kg bw, via gavage	Male and female Wistar rats were dosed with Hydroxydecyl Ubiquinone, starting at 9 and 2 wk before mating, respectively, and dosing was maintained until day 22 after delivery. Females were evaluated on day 13 of pregnancy and day 22 postpartum.	The two higher dose groups displayed transient salivation after dosing, and red-brown urine (attributed to the presence of a metabolite). No adverse effects were observed on estrus cycle, copulation rate, gestation period, parturition, suckling, litter size, pup mortality, morphological and functional development, reflexes, emotionality, spontaneous activity, learning, or reproductive ability after pups reached maturation (statistical significance not provided).	49
Hydroxydecyl Ubiquinone	Rats (males and females; strain and # not specified)	NR	Up to 500 mg/kg d	Fertility and early embryonic development study (details not provided)	A higher rate of post-implantation losses and lower number of live embryos was observed in female rats (statistical significance not provided). No other adverse effects were seen at any dose on reproductive performance or on embryogenesis.	2
Hydroxydecyl Ubiquinone	Rats (strain and # not specified)	NR	NR	Teratology study (details not provided)	Chromaturia (dark colored urine) was the main effect reported. No effect on fetal development or the growth of F_1 animals was observed, and a NOAEL of 500 mg/kg/d was determined (statistical significance not provided).	2

Table 6. Developmental and reproductive toxicity studies

Test Article	Animals/Group	Vehicle	Dose/Concentration	Procedure	Results	Reference
Hydroxydecyl Ubiquinone	Rats (strain and # not specified)	NR	Up to 1000 mg/kg/d	Fertility study (detail not provided)	A slightly higher rate in the of post-implantation losses and lower number of live embryos were seen at the highest dose. Differences between treated rats and controls were not statistically significant. Based on body surface area comparisons, the NOAELs for male and female fertility were determined to be 500 and 1000 mg/kg/d, respectively.	3
Hydroxydecyl Ubiquinone	Rats (strain and # not specified)	NR	NR	Embryofetal study (details not provided)	No differences were seen in the number of visceral and skeletal malformations, and fetal abnormalities, even in the presence of maternal toxicity (statistical significance not provided). Based on body surface area comparisons, the NOAEL for embryofetal development was determined to be 1000 mg/kg/d.	3
Hydroxydecyl Ubiquinone	Rabbits (strain and # not specified)	NR	Up to 150 mg/kg/d	Teratology study (details not provided)	Chromaturia was observed at the highest dose, and no further effects were reported (statistical significance not provided).	2
Hydroxydecyl Ubiquinone	Japanese white rabbits (# not specified)	NR	Up to 500 mg/kg/d	Embryofetal study (details not provided)	One abortion was observed in the highest dose group, but was considered spontaneous due to the spontaneous abortion rate (3%) in this rabbit strain. No statistically significant embryofetal differences were reported between the control and treated groups. Maternal toxicity was evident in this study (both food consumption and body weight gain were suppressed in high dose dams).	3
Hydroxydecyl Ubiquinone	Rats (strain and # not specified)	NR	Up to 500 mg/kg/d	Peri/post-natal studies (details not provided)	Chromaturia was observed in the F_0 generation of the 100 mg and 500 mg pups, and transient hypersalivation occurred immediately after dosing the highest dosage group. No treatment-related differences in body weight, length of gestation, parturition, nursing, and necropsy findings was observed. No treatment-related changes were observed in the F_1 generation or in the dams.	2,3
Hydroxydecyl Ubiquinone	Rats (strain and # not specified)	NR	Up to 1000 mg/kg/d	Peri/post-natal studies (details not provided)	Decreased food consumption and body weight was observed in the high dosage group dams (statistical significance not provided). The NOAEL for pup development was determined to be 500 mg/kg/d (based on body surface area).	3
Ubiquinone	Mice (strain and # not specified; limited details were provided in this review paper)	NR	6, 60, or 600 mg/kg/d, via gavage	Primigravid mice were dosed with Ubiquinone from day 7 to day 13 of the mouse gestational period.	Treatment with Ubiquinone had no effect on fetal death, weight, or postnatal toxicity (statistical significance not provided).	34
Ubiquinone, >98% purity	10 male mice	Composition, not specified	2500, 5000, or 10,000 mg/kg bw, via gavage	Mice were administered the doses for 5 d to test for defects in sperm morphology. A sperm morphology test was performed on day 35 after dosing. Epididymides were minced in phosphate buffered solution and stained smears were prepared on slides. Corn oil and 40 mg/kg bw cyclophosphamine served as the negative and positive control, respectively.	No statistically significant differences were found in the incidence of sperm abnormalities between treated mice and negative controls.	51

Table 6. Developmental and reproductive toxicity studies

Test Article	Animals/Group	Vehicle	Dose/Concentration	Procedure	Results	Reference
Ubiquinone	8 male Wistar rats	Nothing (negative controls) Corn oil (vehicle controls)	10 mg/kg bw/d, via gavage	Ubiquinone was administered via oral gavage for 14 d. Various spermatogenesis and testicular outcomes were compared between the treatment group and control groups. Approximately 5 ml of blood was collected from each rat to measure glutathione, superoxide dismutase, catalase, and malondialdehyde serum levels. Upon sacrifice, testis and epididymis were removed and cleaned, and semen samples were isolated from the cauda epididymal tissue; the left testicle was fixed in Bouin's solution for histological examination and slide preparation, and the right testicle was homogenized and centrifuged to measure various biomarkers.	Except for an increase in seminiferous epithelium heights, no biochemical, histological, or morphological differences were observed between the Ubiquinone-treated, negative control, and vehicle control groups. (statistical significance not provided).	53
Ubiquinone	Rats (strain and # not specified)	NR	6, 60, or 600 mg/kg/d, via gavage	Primigravid rats were dosed with Ubiquinone from day 9 to day 15 of the rat gestational period.	Treatment with Ubiquinone had no effect on fetal death, weight, or postnatal toxicity. (statistical significance not provided).	34

NR- not reported

Table 7. Genotoxicity studies

Ingredient (Vehicle)	Dose/Concentration	Cell/Strain/Species	Method	Results	Reference
			In Vitro		
Hydroxydecyl Ubiquinone*	NR	L5178Y TK +/- mouse lymphoma cells	Mouse lymphoma cells induced with the test substance were assayed to assess the ability of Hydroxydecyl Ubiquinone to induce mutation at the tk locus.	Positive mutagenic responses were not reproducible, dose-related, or statistically significant.	3
Hydroxydecyl Ubiquinone*	NR	Human peripheral lymphocytes	Chromosomal aberration test	Positive results were considered to be related to the redox properties of Hydroxydecyl Ubiquinone, and the test substance was not considered clastogenic.	3
Ubiquinol, 98.7% (acetone)	Up to 5000 µg/plate, with or without metabolic activation	*Salmonella typhimurium* strains TA98, TA100, TA1535, TA1537, and *Escherichia coli* WP2 *uvr*A	Ames test	Not genotoxic	42
Ubiquinol, 98.7% (0.5% w/v sodium carboxymethyl cellulose solution)	6 h: 412-5000 µg/ml 24 h: 141-1201 µg/ml; with or without metabolic activation	Chinese hamster lung fibroblast cell line (CHL/IU)	Chromosomal aberration test. Growth inhibition tests (≥50%) were performed to determine concentration ranges for short term (6 h) or continuous (24 h) treatment.	Not genotoxic. Marked cell-growth inhibition was observed at higher doses in all treatments. Slight increase in percentage of polyploidy cells in all treatments was observed, but not considered significant.	42
Ubiquinone, 99.2% (acetone; water control)	≤313 µg/plate without metabolic activation; ≤1250 µg/plate with metabolic activation	*S. typhimurium* strains TA98, TA100, TA1535, TA 1537, and *E. coli* WP2 *uvr*A	Ames test	Not genotoxic	18
Ubiquinone, >98%	Up to 5000 µg/plate, with or without metabolic activation	*S. typhimurium* strains TA97, TA98, TA100, TA102	Ames test	Not genotoxic	51
Ubiquinone, 99.2% (acetone)	Up to 5000 µg/plate, with or without metabolic activation	*S. typhimurium* strains TA98, TA100, TA1535, and *E. coli* WP2 *uvr*A	Ames test	Not genotoxic. The assay was performed twice. Because precipitates were observed during the first assay, the second assay was performed at doses < 78 µg/plate without activation, and doses < 1250 µg/plate with activation. The number of revertant colonies were not different from those of negative controls and did not show any dose-dependency.	15

Table 7. Genotoxicity studies

Ingredient (Vehicle)	Dose/Concentration	Cell/Strain/Species	Method	Results	Reference
Ubiquinone*	Up to 5000 µg/plate	*S. typhimurium* strains TA98, TA100, TA1535, TA1537, and *E. coli* WP2 *uvr*A	Ames test	Not genotoxic	34
Ubiquinone, 99.2% (0.5% w/v carboxymethyl cellulose sodium solution)	625-5000 µg/plate; with or without metabolic activation	Chinese hamster lung fibroblast cell line (CHL/IU)	Chromosomal aberration test	Not genotoxic. The incidence of polyploid cells was less than 5% in all doses and treatments and judged to be negative.	18
Ubiquinone*	Up to 5000 µg/ml	Chinese hamster lung fibroblast cell line (CHL/IU)	Chromosomal aberration test	Not genotoxic	54
			In Vivo		
Hydroxydecyl Ubiquinone*	1250-5000 mg/kg once or 5000 mg/kg/d	Mice (# not stated)	Micronucleus test. Mice received a one-time dose of 1250, 2500, or 5000 mg, or a daily dose of 5000 mg for 4 d.	Not genotoxic	2
Ubiquinol, 98.7% (corn oil)	500-2000 mg/kg/d	Groups of 6 male Sprague-Dawley rats	Micronucleus test. Rats received two oral doses, at a 24 h interval. Animals were weighed and observed 24 h after the first dose, and sacrificed 24 h after the last dose.	Not genotoxic. No deaths occurred and no clinical signs were observed in any of the groups. Increases in micronucleated polyerythrocytes were not significant.	42
Ubiquinone, >98%	0, 250, 500, 10,000 mg/kg bw	Groups of 5 male and 5 female mice	Bone marrow micronucleus test. Mice were fed their assigned doses for 2 d. Negative and positive control groups were given corn oil and 50 mg/kg bw cyclophosphamine, respectively. Bone marrow smears were collected 6 h after end of treatment.	Not genotoxic	51
Ubiquinone	2000 mg/kg/d	Mice (# not stated)	Micronucleus test	Not genotoxic	34

* Composition not specified
NR- not reported

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