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Chronic effects of swimming pool disinfectants on skin and hair

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Abstract

Swimming offers a myriad of benefits for both physical and mental well-being. As a full-body workout, it engages various muscle groups and promotes cardiovascular health, strength, and endurance. The buoyancy of water reduces the impact on joints, making it an ideal exercise for individuals with arthritis or mobility issues. Swimming is an activity one can ultimately do throughout their entire life because of the low impact which makes it a suitable way to exercise for elderly people to promote longevity. However, swimming can cause dry, itchy skin and atopic dermatitis due to barrier disruption. Chronic exposure to chlorine and its lesser-known byproducts in swimming pools is not widely studied and its negative impact on skin barrier and hair is not generally discussed, underscoring the urgent need for further research and awareness in this area. There is a significant need and opportunities to create new product formulation strategies to address the chronic effects of chlorine and its byproducts on skin & hair.

Keywords: Swimming; Chlorine; Atopic Dermatitis; Disinfection by-products (DBP); Dermal penetration of DBPs; Skin microbiome; Skin barrier; Acne

1. Introduction

Despite the numerous benefits of swimming as a full-body workout and therapeutic activity, the potential adverse effects of prolonged exposure to pool disinfectants cannot be overlooked. Chronic exposure to chlorine and its derivatives in swimming pools pose significant risks to skin and hair health. From dry and itchy skin to increased susceptibility to bacterial infections and potential carcinogenic effects, the impact of chlorine on skin is substantial. Similarly, hair exposed to chlorine often suffers from split ends, discoloration, and increased porosity, leading to further damage.

2. Swimming Pool Water: Chemical Composition

To understand the long-term effect of swimming on skin & hair, it is important to understand the composition of pool water. Maintaining the optimal alkalinity level is vital for ensuring the well-being of swimmers, therefore pH balance of pool water within the safe range of 7.2 to 7.6 is maintained using sodium bicarbonate, sodium bisulfate, or muriatic acid. To ensure a safe swimming environment, disinfectants such as chlorine or bromine are added to the swimming pools. These chemicals work to eliminate bacteria, viruses, and other microorganisms that would otherwise thrive in this environment.

However, when chlorine reacts with water, it creates hypochlorous acid which may react with other substances in the water forming disinfection by-products (DBP). DBPs are ineffective sanitizers and may lead to skin and eye irritation and an unpleasant odor in swimming pools [3]. A recent study identified over 100 DBPs in pool water using gas chromatography/mass spectrometry (GC/MS), photometry, and ion chromatography. Many of the DBPs were new and had not been previously reported [4]. These also include nitrogen-containing DBPs that were most likely formed from

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human inputs, such as urine, sweat, and skin cells [5,6]. Table 1 lists some of the DBPs found in chlorinated and brominated pools [4]. The highest levels of DBPs detected were chloroform and bromoform, both highly toxic substances. While brominated pools contained a low level of chloroform (0.1 μg/L), chlorinated pools contained relatively high levels of bromoform (7.2 μg/L), presumably from the presence of bromide in untreated water before chlorination which then reacts with chlorine that is added during chlorination.

The impact of chlorine and DBPs on the skin can be divided into 3 major categories: 1) Effect of DBPs on Skin/Dermal Penetration 2) Effect on skin microbiome and acne 3) Effect on skin barrier

2.1. Effect of DBPs on Skin/Dermal Penetration

Xu conducted a study investigating the permeation through human skin of DBPs such as Trihalomethanes (THMs), haloketones (HKs), and haloacetic acids (HAA) in chlorinated water, using in vitro diffusion chambers, they reported THMs were approximately 10 times more permeable than HKs. These haloketones and THMs can cause oxidative stress on different layers of skin. Longer-term studies and impact on skin and permeation through the skin are unknown.

Erdinger L et al. studied various pathways of THM uptake in swimming pool-dermal, inhalations, or by swallowing. In an experimental study involving up to 17 participants, they quantified the body burden resulting from exposure to three different concentrations of chloroform in water and air of an indoor swimming pool during a 60-minute exercising period. Chloroform concentrations were measured in blood samples before and after each exercise period. The blood chloroform concentration of participants with scuba tanks was 0.32+/−0.26 μg/l, without scuba tanks 0.99+/−0.47 μg/l, and for persons walking around the pool 0.31+/−0.25 μg/l. These results indicate that the majority of THMs are taken up over the respiratory pathway and a significant amount is also taken up by the skin[7]. In a separate study with competitive swimmers, it was found that dermal uptake accounted for up to 80% of THM blood levels [8].

A cancer study conducted in hospitals in Spain from 1998 to 2001 revealed a heightened risk of bladder cancer among participants who reported ever being in a pool [9,10,11,12]. This elevated risk may be linked to trihalomethanes, which have shown a positive association with bladder cancer [10]. These findings are extremely concerning and display the importance of taking preventative measures to reduce the uptake of DBPs through the skin.

2.2. Effect on Skin Microbiome and Acne

Exposure to chlorine leaves skin dry, leading to itchiness and discomfort driven by the interplay of complex mechanisms. Firstly, exposure to higher-pH pool water increases the skin's native physiologically balanced pH of around 4.7 [13]. An increase in the skin's pH due to the pool may lead to a decrease in stratum corneum cohesion [2] which may lead to microbiome dysbiosis [14]. An increase in skin pH is also known to change the skin's permeability and stripping of essential lipids such as sebum [15], causing dry, itchy, and inflamed skin [16].

In a study conducted on nine women, they found that recreational swimming in pool water significantly decreases sebum levels on the skin [17].

Healthy Sebum composition plays a critical role in maintaining lipid balance and skin barrier, it also protects skin against infections. In fact, Nakatasuji conducted a study where lauric acid, a free fatty acid (FFA) in sebum, was used against the skin bacteria *P. acnes*, *Staphylococcus aureus* (*S. aureus*), and *Staphylococcus epidermidis* (*S. epidermidis*). The results showed that it took more than 15 times less lauric acid to inhibit their growth compared to the amount of benzoyl peroxide (a common antiseptic to reduce bacteria) needed for the same effect. In other words, lauric acid which is present in healthy sebum is significantly more effective than benzoyl peroxide at preventing the growth of these bacteria. [18]. This displays sebum's crucial role in protecting our skin. In addition, lauric acid, palmitic acid, and oleic acid, which are common free fatty acids found in human sebum, boost the production of antimicrobial peptides and increase the antimicrobial activity of human skin cells against the bacteria P. acnes. This indicates that the free fatty acids in sebum help disinfect the skin which enhances the skin's immune defense [19].

Although chlorine may act as a mild disinfectant to acne-causing bacteria, the drying and stripping effects of sebum due to chronic exposure to chlorine may happen due to moisture loss in the stratum corneum from the melting and dilution of the sebum [16], may lead to an overproduction of oil by the skin in an attempt to compensate for the dry skin, potentially clogging pores and contributing to acne breakouts [15].

In a study done on 24 swimmers using fluorescence photography, researchers looked at how bacteria such as C. acnes and Pseudomonadaceae contribute to acne in adolescent swimmers. They found that after swimming, levels of Pseudomonadaceae increased while those of C. acnes stayed the same [20]. This suggests that repeated exposure to

chlorine might affect the balance of bacteria on the skin which could possibly lead to the development of acne in swimmers.

2.3. Effect on Skin Barrier

Swimming can also significantly impact transepidermal water loss (TEWL), indicating compromised stratum corneum [21]. A study involving 58 athletes, including elite swimmers and football players, measured TEWL before, immediately after, and 30 minutes after a 2-hour training session. Among swimmers, the median TEWL levels increased from baseline values of 8.5 $g/m^2/h$ to 14.3 $g/m^2/h$ immediately after training and remained elevated at 13.2 $g/m^2/h$ 30 minutes post-training. Although football players experienced a noticeable increase in TEWL from 8.1 $g/m^2/h$ to 10.6 $g/m^2/h$ immediately after training, which then slightly decreased to 9.7 $g/m^2/h$ 30 minutes post-training, the change in TEWL for swimmers was much more significant [2]. These findings suggest that swimming, likely due to exposure to chlorine and other chemicals in the pool, can damage the skin's stratum corneum, leading to increased water loss and potentially compromised skin barrier function.

Eczema, a condition that affects more than 31 million Americans [22], is a skin condition that leads to itchiness, dry skin, rashes, and even skin infections. Atopic Dermatitis (AD), the most common type of eczema is usually caused by an overactive immune system and it also causes dry and itchy skin. Exposure to soaps and fabric softeners are the common causes that can lead to eczema flare-ups but exposure to chlorine can also give rise to flare-ups. Because chlorine dries out the skin, for some people it will make their skin flare up. In fact, it has been proven eczema is more common in swimmers than people in other sports [23,24,25,2].

A research study was conducted that investigated the impact of residual chlorine in bathing water on the functionality of the skin's outermost layer, known as the stratum corneum (SC) in patients with AD. It found that AD patients showed significantly reduced skin hydration when exposed to bathing water containing chlorine concentrations as low as 1.0 mg/L. Their skin's water-holding capacity was notably affected even at lower chlorine levels compared to NC subjects. This suggests that chlorine exposure may contribute to the development or worsening of AD symptoms in affected individuals [26]. In fact, it has been shown that prolonged contact with chloroform can result in dermatitis [27].

2.4. Effects on Hair

The most common impact of chlorine exposure to hair is split ends due to four key reasons: stripping of natural oils, weakening of hair structure, oxidative stress, and increased porosity. The stiff and crunchy feeling of hair after exiting a pool is due to the chlorine in the pool binding to the protein in hair known as keratin [28]. This binding leads to chlorine stripping hair of its natural oils leaving it dry and brittle. These oils are essential for maintaining the moisture balance of the hair; when the moisture is low the hair is more prone to damage, such as split ends. In addition, oxidative stress from chlorine can also lead to the breakdown of the hair's outer protective layer, known as the cuticle [29] which increases the chance of split ends.

The friction of the water when in contact with hair can also damage the cuticle. In a study conducted on the Japanese National Swimming team using Electron Microscopes (EM), the study found that the cuticle gets damaged due to the friction of the water which leads to the discoloration of hair [29]. Chlorine oxidation is another way that hair gets discolored [30]. During oxidation, the chlorine can react with metals such as copper to form a sticky copper-chlorine complex which attaches to the hair shaft making the hair turn a lighter color for brunettes, and people with lighter hair have greenish hair. In a clinic, they generally found that patients with blond hair who were exposed to copper content from swimming pools along with other factors had their hair turn green [31].

3. Discussion: Opportunities for New Product Innovation

The review above highlights current gaps and the above-mentioned risk factors on exposure to chlorinated and brominated DBPs. Based on the evidence above, product innovation opportunities exist in 3 areas: 1) Reduce the interaction and permeation of DBPs on skin. While the long-term effects of DBPs are not fully known, oxidative stress may be induced by DBPs. Dermal penetration can also lead to systemic exposure to DBPs whose long-term effects are unknown. Strategies to reduce dermal uptake and permeation of DBPs may be beneficial for skin health. One strategy involves creating a physical barrier on the skin, which would minimize direct contact with the skin. One can hypothesize that since sunscreens or compositions with skin-friendly polymeric film formers can form a physical barrier, this may minimize direct contact of DBPs with skin by reducing the diffusion of polymeric film former on the skin.

Even though several swim products currently are offered in the market as moisturizers to treat the symptoms, none of the products today address the root cause and prevention from hundreds of DBPs. Ideal product design would entail creating a barrier water-resistant cream that protects skin from exposure and permeation of DBPs.

- Strategies to maintain pH of the skin and restore the skin microbiome by use of skin-friendly prebiotics or post-biotics or ingredients that restore the pH balance.
- Alternate strategies of pool disinfection methods. Currently, the use of plant-based extracts like Moringa Oleifera [32] for disinfection is being investigated.

Table 1 Free chlorine, chloramine, and THM levels in the swimming pools [4]

	Chlorinated Pools	**Brominated Pools**
Chemical and Concentration	Mean and SD	Mean and SD
Free chlorine (mg/L)	1.28 ± 0.43	0.50 ± 0.16
Monochloramine (NH2Cl) (mg/L)	0.29 ± 0.11	0.27 ± 0.03
Dichloramine (NHCl2) (mg/L)	0.38 ± 0.14	< 0.01
Trichloramine (NCl3) (mg/L)	< 0.10	< 0.10
Chloroform (CHCl3) (µg/L)	15.4 ± 3.5	0.2 ± 0.1
Bromodichloromethane (CHCl2Br) (µg/L)	14.2 ± 4.2	
Dibromochloromethane (CHClBr2) (µg/L)	12.8 ± 4.4	0.4 ± 0.2
Bromoform (CHBr3) (µg/L)	7.2 ± 3.2	2.4 ± 0.2
Total THMs (µg/L)	49.6 ± 10.6	57.2 ± 4.4

4. Conclusion

In conclusion, while swimming offers numerous physical and mental health benefits, chronic exposure to chlorine and its byproducts pose significant risks to skin and hair health. The effects, ranging from dry, itchy skin and acne to more severe consequences like increased dermal permeability and long-term oxidative stress, display the urgent need for further research and awareness. Addressing these issues will contribute to healthier and safer swimming environments, benefiting both individuals and society.

Compliance with ethical standards

No conflict of interest to be disclosed.

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