



Rapid Response

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Rapid Research

Swimming Pool Water Treatment Options

Requested by anonymous lifeguard, Mount Scott Community Pool in Portland, OR

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Request

I'm concerned about whether the chlorine in my local pool might affect my health. What should I be looking for to identify a healthy swimming environment?

Key Findings

Swimming is great exercise and a fun recreational activity accessible to all ages and physical abilities. To protect swimmers, the pool water is chemically modified and controlled, however, pool chemicals may introduce some adverse health consequences:

- As with drinking water, chlorine-based¹ treatment of pool water is used to protect human health. Treatment limits the well-established risk of disease from microorganisms, but introduces a less well understood risk of potential health problems from exposure to chemical by-products of disinfection (DBPs), including very low levels of both known and suspected human carcinogens.
- State regulations vary, but apart from a disinfection requirement, there are almost no specific rules governing the chemical quality or safety of swimming pool water. While the US Environmental Protection Agency (USEPA) has a long-term program to reduce exposure to DBPs from drinking water, their level is not regulated in swimming pools.
- There is good evidence to suggest that DBPs in the swimming environment increase the risk of respiratory ailments like asthma and possibly increase the risk of some cancers.
- The disinfection process (e.g., UV, salt-water-generators, ozone, etc.) is only one factor affecting water quality. A healthy pool environment requires good pool chemistry control, good maintenance, and sound ventilation practices (for indoor pools). The quality of pool operation is likely more important to swimmer health than the specific disinfection method.
- Wide-spread press coverage of public pool and water park disease outbreaks from chlorine-resistant organisms, such as *Cryptosporidium* spp. (Crypto), has been a strong driver of improved pool sanitation methods. Both UV and ozone-based methods can inactivate Crypto, and are usually used in conjunction with added chlorine. These methods may reduce the exposure to some types of DBPs, but may increase exposure to others.
- Good swimmer behavioral practices, e.g., showering with soap before pool entry, not swimming while sick, and limiting water contamination from urine, feces, sunscreen, etc., can reduce the load on the pool treatment system and help maintain pool water quality.

¹ Chlorine-based chemicals and chlorine will be used interchangeably, recognizing that in most cases the added treatment chemical is some chlorine-containing chemical compound rather than pure chlorine itself.

Suggested Actions for Those Concerned about Water Quality at their Pools

- Follow and encourage the good behavioral practices for swimmers mentioned above.
- Swimmers should be concerned when pool environments have strong odors and high incidence of eye, nose irritation, etc. These are signs of an increased risk to health from poor pool air quality and should be brought to the attention of pool management. If you (or especially your children) are frequent swimmers and experience health symptoms, we recommend the following:
 - Talk with the pool manager about their disinfection methods and pool maintenance procedures. Ask about whether they are taking measures to reduce exposure to DBPs.
 - Check with other frequent swimmers or parents of swimmers for similar reactions or sensitivities. Dealing with management as a group may be more effective in getting your concerns addressed.
 - Investigate other nearby pools for better environmental conditions. If you find an alternative, let the pool know why you are switching. When in doubt, vote with your fins!

Background

Most swimming pool water in the US is disinfected with some form of chlorine. Chlorine disinfection helps to prevent the spread of water-borne illness from organisms like *E. coli* and Norovirus, but chemical treatment also has some unintended negative health consequences. Treatment creates potentially harmful chemical by-products known as DBPs (disinfection by-products). DBPs may enter the body through the mouth (from swallowing pool water), but also by absorption through the skin or by inhalation.²

The same issues arise with drinking water, where DBPs occur due to the reaction of chlorine with naturally-occurring organic material in ground or surface water.³ While most DBPs are at very low levels in well-maintained water-treatment systems, concerns over long-term chronic exposures led the US Environmental Protection Agency (USEPA) to restrict the permissible level of common DBPs in drinking water,⁴ however, there are essentially no restrictions on the level of DBPs in swimming pool water.⁵

In pools, DBP levels may be higher than in drinking water for several reasons. Swimmers continually introduce new contaminants to pool water, including sweat, urine and fecal matter (especially in children's wading pools), but also synthetic contaminants from sunscreen, lotions, etc. To deal with on-going contamination, a level of residual chlorine is maintained at three- to ten-times the level of normal drinking water. In addition to killing microorganisms, chlorine-based chemicals oxidize (break down) many contaminants to harmless substances like nitrogen or carbon-dioxide gas. If contaminant breakdown is incomplete, due to heavy swimmer use (overloading the system) or poor pool chemistry control, DBPs can accumulate.

The risk of exposure to DBPs is greater for indoor pool environments, where ventilation may be limited. Volatile DBPs like nitrogen trichloride easily escape the water on their own, but additional features like sprays or wave-makers can generate aerosol droplets leading to higher airborne DBP levels. As room air is often recirculated to reduce heating or cooling costs, DBPs can concentrate over time leading to complaints of odors and eye or respiratory irritation.

While chlorine-based pool water treatment is both highly effective and inexpensive, concern over the health effects of DBP exposure and threats from chlorine-resistant microorganisms have led to the introduction

² In the home, there is significant human exposure to chloroform (a DBP and suspected carcinogen) from showering! High water temperatures and large contact area of sprays vaporize some DBPs and they enter the body with normal breathing.

³ DBPs include trihalomethanes (THMs), such as chloroform, chloramines, haloacetic acids (HAAs), and bromine compounds (where bromine is used for disinfection or occurs naturally in the water), among others.

⁴ The Stage 2 Disinfectants and Disinfection Byproduct Rule introduced new standards for various DBPs, including THMs and HAAs. The Long Term 2 Enhanced Surface Water Treatment Rule addresses water-borne illness from microorganism, such as *Cryptosporidium spp.*

⁵ For example, the Washington State Board of Health specifies only that chlorine be between 1.5 and 10 ppm, with chloramines no more than 50% of the level of chlorine. Furthermore, "[o]wners shall maintain water free from harmful levels of disease producing organisms, toxic chemicals, or adverse physical conditions" (34).

of non-chlorine technologies like ozone and ultraviolet light (UV) treatment. Unfortunately, neither of these methods provides any *residual* disinfection capability in the treated water, so even with these systems, a small amount of chlorine-based disinfectant is added as water enters the main pool.

Health Concerns in Swimming Pool Environments

In the typical public or fitness club pool, swimmers are immersed in a soup (albeit dilute) of treatment chemicals, which may include sanitizers, oxidizers, algacides, chlorine-stabilizers, and other water conditioning chemicals. Adding to the mix are a vast number of other substances, including DBPs, lotions, personal-care products, and various microorganisms and organic contaminants (e.g., skin or hair) from the swimmers themselves. As a result of this contamination, even a well-run and maintained pool poses some risk to human health.

Recreational Water Illnesses

The primary concern of most pool operators is the risk of recreational water illness (**RWI**) from microorganisms. Thousands of people each year are affected by RWIs, in some cases only a “swimmer’s itch,” but infections with dangerous pathogens have led to both hospitalization and death (1). In 2007, there were over 1900 cases of infection with *Cryptosporidium spp* (Crypto) in the state of Utah alone, primarily in the Salt Lake City area. Crypto is a particular challenge because it is resistant to disinfection with chlorine (2).

Creating a safe swimming environment is a shared responsibility of pool operators and swimmers. Effective pool disinfection is more easily maintained if the contaminant load is kept to a minimum through behavioral practices, such as showering with soap before swimming and encouraging frequent bathroom breaks (3). Identifying and responding to accidental pool contamination events, such as fecal releases, is critical and typically requires pool closure for cleanup and superchlorination.⁶

In spite of the well-known risk of RWI, repeated surveys of water conditions have shown that many pools fail to meet health code standards for water quality, including findings of significant numbers of pools with no active-chlorine disinfectant present (4; 5). While perhaps two-thirds of RWI outbreaks involve Crypto, 25% or more of the quantified disease is from organisms easily inactivated by chlorine (1). These data suggest that poor swimming pool maintenance is putting swimmers at risk of RWI.

To deal with the increasing incidence of RWI, the Centers for Disease Control and Prevention (CDC) has suggested adding UV or ozone treatment systems to pools and strengthening the response to accidental contaminant releases (6).⁷ Following the 2007 Crypto events in Utah, new UV and new ozone treatment systems were installed in 40 pools in Salt Lake County (7).

Asthma and Respiratory Problems

One of the most common DBPs, nitrogen trichloride, is a known trigger for asthma symptoms (8). Nitrogen trichloride and related chloramine compounds are also primarily responsible for the odor and skin, eye, throat or nose irritation reported by swimmers, lifeguards and non-swimmer companions in pool environments. As described earlier, the build-up of DBPs is a particular problem for indoor pools, where interactions between deteriorating pool water quality and ventilation practices can lead to high DBP exposure (9).⁸

New research and comprehensive reviews of respiratory health issues suggest that exposure to DBP-containing pool air increases the frequency and severity of asthma, allergic diseases and acute respiratory problems (10; 11). Young children are likely to be especially vulnerable. One study states bluntly that, “[w]e

⁶ Super-chlorination is the one-time application of a large dose of chlorine. Dose may vary depending on the reason for treatment. A fecal incident may require higher levels for longer periods of time. Because of the special conditions in spas, super-chlorination or -bromination (where bromine is used) may occur daily (35).

⁷ UV and ozone systems are also being added to drinking water treatment systems where chlorine-resistant organisms like Crypto appear in local raw water sources. Seattle’s Cedar River Water Treatment Facility has a coupled ozone/UV system and was installed to meet pending EPA drinking water standards.

⁸ In addition to the occupational risk for lifeguards and pool staff, problems have also appeared in food workers, where chlorinated-water is used for washing during processing of poultry, raw vegetables, etc.

cannot see any good reason why babies should swim in (chlorinated) pool water” (11). One study notes that, “[t]richloramine accumulating in the air of indoor swimming pools is one of the most concentrated lung toxicants to which children of developed countries are regularly exposed” (12). Most recently, the risk of asthma and respiratory symptoms were compared for young swimmers (ages 13-18 years) in two types of pools: 1) chlorine-based disinfection and 2) copper-silver disinfection (13). Respiratory symptoms increased with the degree of pool exposure for swimmers in chlorine pools, but there was no association between respiratory symptoms and exposure to copper-silver disinfected pool water.

While the causal link between pool air quality and problems like asthma is not conclusive, the evidence suggests good reason for concern. Swimmers should be aware of the risks from poor indoor air quality at swimming centers. Frequent complaints of odor and irritation are signs of poor pool air and water quality. Swimmers should bring their concerns to the attention of pool operators and managers. As possible solutions, the CDC recommends improved ventilation and the addition of UV or ozone treatment to help reduce the level of DBP-irritants (14).

Cancer

It has long been known that chlorinated-water contains low levels of probable or possible human carcinogens (15). To minimize health risks, regulators have increasingly restricted the level of some DBPs allowed in **drinking water**. As standards have tightened, water-system operators have made changes to treatment chemistry and introduced new technologies, like ozone and UV treatment, to improve disinfection and reduce drinking exposure to DBPs.

In **swimming pools**, DBPs are more varied in chemical composition and may be present at higher concentration than in drinking water; the most recent studies have identified carcinogens and substances with estrogen-like activity (16; 17; 18). In 2007, Villanueva et al. published the first epidemiological study of swimmers and cancer from DBPs. They found a 1.6-fold increase in the risk of bladder cancer for swimmers versus non-swimmers (19). The Villanueva study is important because it demonstrates that the increased risk comes from exposure to DBPs **through the skin** rather than from drinking pool water.

Other recent studies have addressed the **theoretical** cancer risk from DBP exposure during swimming. In a 2008 study, pool chemistry variables and levels of common DBPs, including chloroform, were gathered from 183 indoor pools (20). By combining measured pool DBP levels with widely-accepted exposure-risk estimates, researchers found that cancer risk can exceed the one-per-million lifetime maximum set by the USEPA for some common pool DBPs, especially for **inhalation exposures**. The risk varied depending on the type of pool water treatment.

The studies cited above are recent and increased confidence in the results will come in time as the research is advanced by other investigators (21; 22). While some of the identified risks are quite small, they demonstrate a new understanding of chemical exposures from swimming, via the air (by inhalation) and water (through the skin) to recently identified DBPs. PPRC believes this is sufficient to warrant a heightened concern for health risks in the swimming environment.

Water Treatment for Swimming Pools

The growing awareness of a potential link between pool water quality and swimmer health has sparked a shift away from simple chlorine-based treatment to new treatment methods and more complicated multi-stage treatment systems. While much of this development has occurred in Europe, US pool operators are increasingly embracing these new technologies. What options are there to achieve good disinfection while minimizing exposure to DBPs?

The Treatment Process

It may help to think of a pool as a large chemical reactor. The goal of pool operator is to maintain a healthy pool environment by controlling the chemistry in the reactor. To accomplish this, a small fraction of pool water is continuously cycled through a set of treatment processes. Depending on the pool, one or more of the following operations may be part of the overall treatment system:

- Pre-treatment filtration – Filters can trap organic matter like skin, hair or dirt before it has a chance to react with treatment chemicals, reducing chemical demand and limiting the raw material of DBP formation. Filters can also trap microorganisms like Crypto, which reduces the level of microbes in pool water and helps minimize the chance for cross-swimmer infection.
- Sanitation – After filtration, the remaining microorganisms must be killed or inactivated. The most common choice for sanitation is added chlorine, but UV-light and ozone treatment are also effective sanitizers. Unfortunately, the effects of UV and ozone do not last past the treatment zone, so they are followed by addition of a chemical sanitizer, usually chlorine.
- Oxidation – Organic contaminants not captured by the filter must be eliminated before they react to form DBPs. Chlorine, ozone and UV all work to varying degrees to break down chemicals and some recirculated DBPs in pool water. Many chemical contaminants are converted to nitrogen or carbon dioxide gas and leave the pool harmlessly. Others may resist breakdown and build-up in pool water.
- Post-treatment filtering – In some pools, activated-carbon filters or active-carbon injection (with subsequent filtration) are used after disinfection and oxidation, to remove DBPs. This is common in Germany, which has the highest standards for pool water quality, but is rarely found in the US (23).
- Residual chlorine addition – In a typical design, it takes about 6 hours to run the pool volume through the treatment system once, but in reality, because of pool mixing, less than one-half of the pool volume actually sees treatment in a single cycle (24). For this reason, health codes require that pools maintain a minimum level of chemical disinfectant in the water at all times, usually some form of chlorine. This added “residual” disinfectant is a critical layer of protection for swimmers (23).
- Miscellaneous chemical addition – A variety of other chemicals are used in pools, including chlorine stabilizers and algaecides (mainly for outdoor pools), chemicals to control the acidity (critical for effective chlorine function), shock treatment chemicals (often high doses of chlorine, used after fecal releases and other accidents or for DBP build-up), and others.

How Treatment Affects DBP Levels

Basic Chlorine-Pool Operation

All common pool treatment systems contain some level of DBPs, because disinfection and oxidation chemical reactions are continually at work in the main body of the pool.⁹ The most important means of limiting DBP exposure is to minimize their formation by maintaining good control of pool chemistry. The dynamic nature of the pool environment, as the number and type of swimmers change over time, can make it difficult for operators to balance treatment with the changing contaminant load.

The effectiveness of added residual chlorine, required by code in nearly all public pools, is very sensitive to pool chemistry, especially the pH or acidity. While there are automated sensors and treatment systems in some pools, many locations do all control and testing manually. Whatever the system, there are always opportunities for errors, equipment or human failures, or inattention to cause pool chemistry excursions. Time lags between measurements and adjustments can also make it difficult to keep up with the needed adjustments.

When pool chemistry is out-of-control, DBP levels will rise, sanitation chemical reactions may become less effective, and swimmer risk increases. As mentioned earlier, these out-of control situations should not be considered normal pool operation. Controlling DBPs in the water is the first step to keeping indoor pool air healthy (25). Routine incidence of irritation or strong odor is unhealthy and should be brought to the attention of pool management.

In addition to maintaining proper chemistry, a number of other factors can be controlled to prevent or limit DBP exposure, including fresh water addition, physical pool cleanliness, good filter maintenance, enforcing hygiene rules, etc. Given the increasing focus on inhalation risk from DBPs, it is especially important that ventilation be stepped up when necessary to minimize DBP exposure.

⁹ While there are non-chlorine based systems, they are rare in public or fitness center environments. Some less common treatment systems with links to resources appear in the Resource section below.

There is some experience, especially in Europe, for reducing DBP exposure by lowering the average residual pool chlorine level (18). To maintain safe sanitation levels (i.e., sufficient active-chlorine levels), pool acidity must be adjusted and more tightly controlled.

The Effect of Chlorine Source

There are a number of ways to add chlorine for pool treatment, but the differences in DBP formation are minor.¹⁰ The choice of chlorine type is usually driven by costs at the time of pool installation or operational issues.

In recent years, onsite chlorine generation (also known as saline generator systems) has been increasing in popularity, especially for home pools (26). These systems generate chlorine-compounds by electrolysis from a low concentration of salt (sodium-chloride) dissolved in the pool water. PPRC found no independent scientific literature of DBP products from saline generation, but as the chlorine-compounds produced are essentially identical to conventional solid or liquid-dosed chlorine treatments (27), the disinfection by-products should be similar to standard chlorine-pool DBPs. While onsite chlorine generation may be desirable for certain operational benefits (e.g., less hazardous chemical handling (28)), the pools are not inherently healthier than other pools.

A related electrolysis technology, electrochemically-generated mixed-oxidant disinfection (EGMO), has been applied to pools in the US and abroad (29). Twenty-five EGMO pools were included in the Korean study of cancer risk from swimming cited above (20). While the levels of some DBPs were lower in EGMO pools than for regular chlorine pools, there were higher concentrations of other DBPs (with a roughly 30+% increase in overall DBP level). Still, the chlorine pools had a higher estimated cancer risk because of their higher concentration of volatile DBPs (increased inhalation risk versus EGMO pools).

EGMO vendors claim that their systems reduce levels of DBPs. The Korean study suggests this may not be true in practice or, it may depend on unknown variables, and perhaps, precisely which DBP-components are measured and reported. The study is a good demonstration of the complexity of sorting out risks from DBPs in swimming environments.

UV Treatment

Adding new layers of treatment can improve the chances for good pool health. UV systems are increasingly common, partly in response to the rising awareness of Crypto infection risk. UV treatment can break down common DBP irritants like chloramines, which can lead to an overall reduction in chlorine use, a significant side benefit. While it is commonly accepted that UV treatment does not generate DBPs, recent research suggests that it does, though the levels are below World Health Organization standards for drinking water (30).

The operational details are important to determining whether a UV system will be effective. The system must be sized properly. Some installed UV systems may use low pressure lamps, which are effective for disinfection, but not for DBP control. And while medium-pressure lamps do reduce some DBPs, pools can opt for low-power disinfection that will not break down DBPs. It is not practical for the average swimmer to access this level of operational detail.

Ozone Treatment

Similarly, ozone is very effective at both oxidation and sanitation, and is useful for reducing production of some DBPs. The Korean study of 183 pools, cited earlier, showed a nearly 40% reduction in measured DBPs (total trihalomethanes) with ozone/chlorine versus chlorine-only systems (20). As a result, the ozone/chlorine combination had the lowest overall theoretical cancer risk.

¹⁰ An exception is chlorine dioxide gas which disinfects by a very different mechanism and does not produce the broad range of DBPs formed by other chlorine-based pool disinfectants. On the other hand, for swimming pools, chlorine dioxide is usually used in conjunction with another form of chlorine for residual protection.

Ozone chemical action is known to form some unique, potentially hazardous DBPs at low levels (31). In Germany, ozone is used extensively as part of a best-available-technology approach to pool water treatment. In ozone systems there, activated carbon injection and filtration are used after ozone treatment to remove residual chemicals and DBPs from the treated water before it enters the pool (23).

Conclusions

Swimming is said to be the second most popular recreational activity and swimmers enjoy significant benefits from regular aerobic exercise. In order to keep swimmers safe from RWI, disinfection is required by state health codes, but creates health risks from exposure to disinfection by-products. These DBPs are present at very low levels, but include likely human carcinogens.

For the closely related problem of drinking water safety, the USEPA has taken significant action to reduce exposures by forcing improvements in monitoring and disinfection technology. Recent research shows that the risks to regular swimmers may be greater than for drinking water exposure, yet there is essentially no regulation directed at reducing DBP exposure to swimmers.

Pool operators are primarily focused on RWI risk, but they have tools available to minimize swimmer risk from DBPs, including careful pool chemistry monitoring and control, good ventilation practices, and enforcing good behavioral practices. If the available methods are inadequate, well-developed retrofit technologies, like UV-water treatment, are available that can help manage DBP problems.

To increase personal safety, swimmers should look first for well-run, well-managed pools. Overall cleanliness and good adherence to behavioral rules, like showering before swimming, are important to a healthy pool environment. A low, even swimmer load is probably more predictable and therefore easier to keep in good chemical control. Unsafe conditions may develop many hours after a high-load period, so an empty early-morning pool is not necessarily a healthy pool.

Frequent experience with bad indoor pool air and regular eye or nose irritation for large numbers of swimmers indicate an unhealthy pool environment and should be of concern. Pool operators have many tools to maintain swimmer safety, e.g., increasing fresh water use or fresh air intake and increased monitoring and control of chemistry. If a pool treatment system is under-designed, there may be no alternative but to limit swimmer load (restrict the numbers of swimmers) or to invest in new technology, for example, the addition of UV treatment or improved filtration. Alert, educated swimmers should interact with public and fitness center pool staff to make them aware of problems and help maintain a healthy environment for all.

Items for Further Research

- Spas/Hot tubs – The higher temps and higher bather loads of spas and hot tubs require a higher level of treatment and may use different chemicals for disinfection, such as bromine, that form different types of DBPs.
- Pool Ionization (silver/copper ion pools – Some state health codes permit the use of silver and copper ion generators for pool sanitation. While these systems are chlorine-free, metal ions do not oxidize contaminants, so a separate chemical oxidizer (often chlorine) must be used (32).
- “Green” pools – Aquatic plants can provide limited “natural” water treatment for small, private pools with low bather use, perhaps in conjunction with UV or silver/copper ion systems (33; 34).

Resources

- The USEPA has a great deal of information on water treatment and DBPs. Many of the issues are discussed in an in-depth (if somewhat dated) review of disinfection technologies: http://www.epa.gov/ogwdw/mdbp/alternative_disinfectants_guidance.pdf
- The World Health Organization has an excellent recent report on swimming pool health issues and water treatment: http://www.who.int/water_sanitation_health/bathing/srwe2full.pdf
- Typically brief Wikipedia article on swimming pool sanitation: http://en.wikipedia.org/wiki/Swimming_pool_sanitation

- There are pool-oriented magazines with online content, but these advertising-driven publications often include articles written by vendors to promote their own products, e.g.:
Aquatics International - <http://www.aquaticsintl.com/>
Pool & Spa News - <http://www.poolspanews.com/>
- For private pool owners, there are active pool forums that discuss issues of pool chemistry control and treatment options, e.g.: <http://www.poolspaforum.com/> ; <http://www.troublefreepool.com/>

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