Paper 10.3

Probabilistic modelling of chlorination by-product risk from indoor swimming pool use

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Synopsis

While chlorination helps ensure a safe indoor swimming environment, it also leads to the formation of compounds of known toxicity. Swimming pool attendants take up some of those compounds through breathing or dermal contact. The amounts may be modelled to derive exposure estimates by type of swimming pool use (competitive swimmers, frequent swimmers, occasional swimmers, non swimming attendants). Competitive swimmers appear to have the highest estimated absorbed trihalomethanes (THMs) per trimester (e.g, chloroform: median, 12 μg/day; 95th percentile, 55 μg/day). Frequent swimmers may have higher absorbed doses over a life-time, which are as high or higher than reported levels of positive association with disease risk.

Introduction

Chlorine is widely used to ensure protection from microbial hazards in swimming pools. It is well known, however, that chlorination of water causes the formation of by-products, collectively named disinfection-by-products (DBPs). Toxicological studies have revealed the toxic properties of some of these compounds, while epidemiological research has associated chlorination, and some DBPs, to adverse health outcomes, including bladder cancer and some pregnancy-related outcomes. A recent study (1) has identified a positive association, between ever attending a swimming pool and bladder cancer.

While hundreds of DBPs exist, the most studied and well-known are trihalomethanes (THM), including chloroform (CH3Cl), dibromochloromethane (CHBr2Cl), bromodichloromethane (CHBrCl2) and bromoform (BrCH3). These compounds have been identified in indoor swimming pools, in water and air (2) (3). Chloroform, reportedly the most abundant of the four main THMs in the swimming pool environment, has been identified in both breath and blood of swimming pool attendants (2) (3). While it is difficult to relate swimming pools attendance with risk of disease, probabilistic exposure models, together with reference values for toxicity, e.g. (4), provide insight in the significance of the risk for swimming pools attendants.

Materials and methods

THM concentration in the water of swimming pools have been collated from (5), and modelled according to a log-normal distribution. Other studies provide data on chloroform, but the relationship between chloroform and other THMs does not seem well established for swimming pools to allow extrapolation. NHAPS data (6) were used to model the duration of each swimming event; half of the swimming events have been assumed to last more than 51 minutes, with a geometric standard deviation of 3, under a log-normal distribution, truncated at 3 hours per swimming event, and re-estimated. The same swimming duration was assumed for all categories of interest (competitive swimmers, frequent swimmers, occasional swimmers, swimming pool attendants). Swimming frequency was modelled according to (6), with different distributions according to swimmer type. For competitive swimmers, in each trimester swimming frequency was equally likely to be from 3 times a week up to 6 times a week. For frequent and occasional swimmers, it was assumed that the same distributions used for women by (6) would be applicable. Non-swimming attendants were equally likely to attend once a week up to twice a week, assuming that many would be parents of swimming children. Absorption rates were estimated from the change in blood levels of chloroform in (2) and (3), taking into account the blood volume, the duration of exposure and the water chloroform concentration; they were modelled with a uniform distribution. For other THMs, uptake rates were estimated by applying a chloroform/single THM ratio from experimental studies to derive a point-estimate of the absorption rate. Absorbed dose of individual THMs per trimester per type of swimmer was calculated as the product of swimming frequency, swimming duration, concentration of THM in water and uptake. Since swimming pool attendance is potentially a life-long behaviour, the exposure of a trimester was projected to life-time exposure. Occasional or frequent swimmers were presumed equally likely to swim for a trimester only, for every trimester from age 18 to age 65, and any possible interval in between. Competitive swimmers, where no age boundaries were applied, were assumed to swim at least one year (minimum) to a maximum of 15 years, with a most likely value of 5 years.

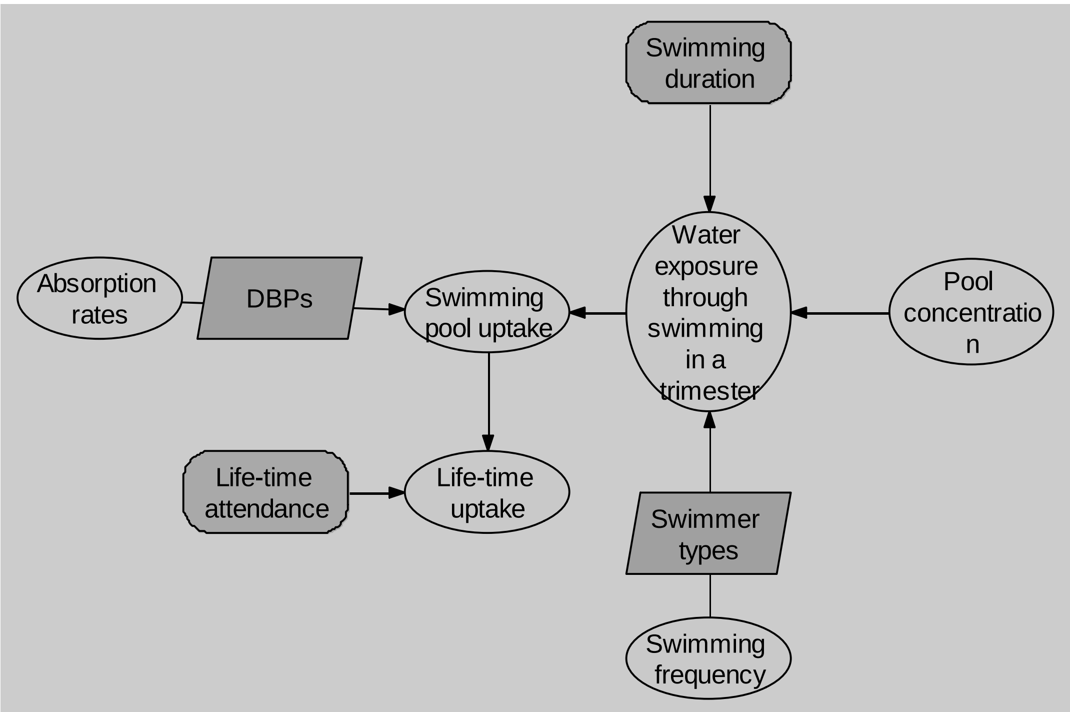

Figure 1 Structure of the model.

People attending only were assumed to participate in the activity for maximum 10 years.

The model structure is reported in Figure 1. Life-time exposure estimates were compared with reference values provided by (4).

Results

According to the model, the simulated swimming pools have median chloroform concentration of 113.3 µg/L; only 5% of the swimming pools have levels exceeding 217 µg/L. Average duration of swimming pool attendance was simulated at 61 minutes, with a quarter of the events lasting less than 21 minutes and a quarter lasting more than 85 minutes. Median frequency of swimming was 1.5 times per trimester for occasional swimmers, 2 times a week for frequent swimmers, 4.5 times a week for competitive swimmers, whereas non swimming pool attendants would be present 6 times a month.

For chloroform, competitive swimmers had the highest median uptake per trimester, while occasional swimmers had the lowest uptake (table 1). Frequent swimmers and attendants were in between. Similar trends apply to the other three THMs, albeit at much lower values.

Table 1 Distribution of estimated chloroform absorbed doses (mg) per type of swimming pool use, per trimester.

	Occasional swimmer	Frequent swimmer	Competitive swimmer	Swimming pool attendant
5-th percentile	1.0	24.9	198.2	15.1
25-th percentile	3.9	99.92	485.6	44.1
50-th percentile	17.5	269.7	1060.0	80.4
75-th percentile	38.2	742.4	2211.0	218.8
95-th percentile	134.0	3041.0	5000.0	505.8

The median daily uptake for competitive swimmers is 12 µg/day, which corresponds to a 2.2 µg/L change in blood chloroform levels from the start to the end of the activity. At the 95-th percentile, the dose per day is averaged at 55 µg/day.

Exposure scenarios are projected over a life-time in table 2. The absorbed dose for frequent swimmers is higher than for competitive swimmers, given the shorter practice span assumed for competitive swimmers.

Table 2 Distribution of estimated chloroform lifetime absorbed doses (mg) per type of swimming pool use.

	Occasional swimmer	Frequent swimmer	Competitive swimmer	Swimming pool attendant
5-th percentile	24.04	889.3	2755	134.6
25-th percentile	229.1	7146	1.2×10^4	609.9
50-th percentile	1083	2.3×10^4	2.7×10^4	1543
75-th percentile	4626	7.1×10^4	7.2×10^4	4273
95-th percentile	1.4×10^4	2.2×10^5	1.3×10^5	9562

Lifetime absorbed doses (table 2) can be used to estimate the Lifetime Average Daily Exposure, LADD (4), which can be compared with reported levels at which a positive association with cancer ($0.7–2.14 \times 10^3$) or adverse pregnancy-related outcomes ($0.2-2.3 \times 10^3$) has been found (5). When values of table 2 are transformed into LADD, more than half of frequent swimmers and competitive swimmers appear to exceed the levels reported as with a positive correlation with disease. The same applies to total THM levels, but not for CHBrCl2.

Discussion

At the swimming pool water levels of chloroform modelled in this study, the estimated dose of chloroform and total triahalomethanes is higher than reference values recently used in a DBP risk assessment (4).

Competitive swimmers are expected to internalize higher levels of all THMs, compared to other swimming pool users, when a trimester is used as a reference period. This seems to be the combined effect of frequent swimming, longer duration of attendance, and higher absorption rates. The finding is in line with (2).

When results are projected over a life-time, excluding childhood, people who swim regularly appear to potentially uptake more THMs than competitive swimmers, if it is assumed that competitive swimmers cease swimming pool use when their competitive activity ends. All other swimming pool uses, under the conditions tested, appear to have much lower estimated doses of THMs.

There is substantial uncertainty in the estimates. Estimating uptake from water concentration is prone to a number of uncertainties: the same THM water concentration, due, for example to different ventilation practices, may result in different uptake by swimmers, especially for inhalation.

Disinfection practices may change over space and time. The THM concentration levels used in the model are, for chloroform where such comparisons can be made, in line with the range summarized in (6); however, the sample used is relatively small, and the median value larger than the across-study median reported by (6) (113.3 versus 52.2). More recent results may yield lower estimates of absorbed doses.

Other DBPs may occur in a swimming pool other than THMs; nevertheless, since for the other DBPs of concern (haloacetic acids, etc), ingestion is believed to be the most significant route of exposure, they may be less of a concern in the swimming pool environment.

Swimming pool workers may be more at risk than swimmers or other attendants, as their exposure involves longer hours and may continue over decades of employment. However, the population was not the target of the present study, and may be addressed in future research.

Future refinements in the model will include alternative ranges of water THM concentration, and a combination with other exposures such as showering, drinking, bathing, etc..

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