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CORRELATION ANALYSIS OF FLUORIDE LEVELS AND COGNITIVE TEST PERFORMANCES IN THE ADULT POPULATION EXPOSED TO WATER CONSUMPTION WITH HIGH CONCENTRATIONS OF FLUORIDE

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ABSTRACT: Intake of 2 milligrams per liter (mg/L) of fluoride (F) alters brain biochemistry and morphology. This paper evaluates the effect of water consumption with high levels of F on non-verbal intelligence in young adults from several cities in México. Such locations were chosen as they exhibit normal to exceptionally high F levels in water: León, Guanajuato, México, with F concentrations of 1.17 mg/L, Unión de San Antonio, Jalisco, México, (2.8 mg/L), Lagos de Moreno, Jalisco, México, (3.3 mg/L) and Teocaltiche, Jalisco, México, (6.8 mg/L). Different from other research studies, this one included participants aged 18, all from similar socioeconomic backgrounds who had lived in the study locations for at least 14 years. For each individual, F concentration in urine was measured and the Beta III test was conducted. The F concentration in the urine of the participants from León was 1.0 ± 0.4 mg/L, in Unión de San Antonio, 1.3 ± 0.5 mg/L, in Lagos de Moreno 2.8 ± 1.9 mg/L and Teocaltiche 6.4 ± 0.7 mg/L. An average IQ of 90 was recorded in León, 84 in Unión de San Antonio, 83 in Lagos de Moreno and 80 in Teocaltiche, with a significant difference of 10 points between León and Teocaltiche (data are expressed as geometric mean±. standard error). An inverse relationship between the IQ and the concentration of F in the urine was obtained.

Keywords: Beta test; Endemic fluorosis; Fluoride; IQ.

INTRODUCTION

Humans are greatly exposed to F[1-3], although it is considered that daily intake depends on the consumption of F in salt and drinking water, plus their exposure to F-enriched articles [4]. The optimum level of F intake recommended in tap water is 0.7 to 1.5 mg/L[5] according to the World Health Organization, 2006 (WHO), whilst Mexican Official Standards [(NOM) NOM-127-SSA1-1994, Environmental Health. Water for human use and consumption} give the permissible limit as 1.5 mg/L][6]. Los Altos Norte de Jalisco (LAJ) in México, has its main drinking water supply coming from deep wells, sourced by hydrothermal waters[7], and among other uses it is used for cooking. This is an area that presents endemic fluorosis (i.e., levels of drinking water > 1.0 mg/L of F[7]).

The main route of incorporation of F in the human organism is the digestive one. It is rapidly absorbed into the mucosa of the small intestine and stomach by a simple diffusion phenomenon. The F contained in drinking water is absorbed almost

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completely (95–97%) and the F bound to food is absorbed to a lesser extent. It has long been shown that water is the main source of ingested F. Plasma concentrations of F in healthy young or mature fasting adult individuals are numerically similar to the F concentrations in drinking water and the plasma F concentration tends to increase slowly with age[8,9].

A large number of studies both clinical[10-14] and experimental[15-21] report health effects affecting the brain and neurological activity from the intake of high concentrations of F in water. In particular, research performed in endemic fluorosis areas suggests an inverse association between high F exposure and children's intelligence[1,22-24] and cognitive development delays[25].

However, most of the reported studies evaluate the child population, therefore, the present study evaluates the cognitive performance of young individuals who have been exposed to high levels of F for over 14 years in the LAJ region, thus further exploring if brain damage caused by F contamination prevails throughout adult life[4,26].

MATERIAL AND METHODS

Four locations were chosen based on previously reported normal to exceptionally high F concentration in tap water (see Table 1) (i) León, Guanajuato, México; (ii) Unión de San Antonio (Unión), Jalisco, México; (iii) Lagos de Moreno (Lagos), Jalisco, México; and (iv) Teocaltiche, Jalisco, México. León was considered the control group as it was very close to the other municipalities and presented the lowest concentration of F, within the limits set by the NOM 127 [6]. The study design was non-experimental, cross-sectional, and correlational.

The sample was calculated using the X-Sectional, Cohort, & Randomized Clinical Trials Method. The confidence level and the power of the two sides were 95 and 80%, respectively. The calculation was done in Open Epi. This one included participants aged 18, all from similar socioeconomic backgrounds which had lived in the study locations for 14 continuous years. The sample size was 1,100; of which only 946 completed all the tests, 535 women and 411 men, 90% were endemic and no consumption of antipsychotics, anxiolytics, and anticonvulsants.

Water samples were collected from the tap of each participant's house. Similarly, urine samples were requested from the participants, collected in sterile polypropylene cups, and kept at 4ºC. Determination of F in water tap and urine was performed as described in NIOSH 8308 procedure[27]. The precision obtained was 98 ± 3% mg/L.

Beta III intelligence

One of the most explained concepts in psychology is intelligence and can be defined as the ability to solve problems. Catell's proposed two-factor theory proposes two factors: fluid intelligence (Gf) of cognitive processes and crystallized intelligence (Gc) of knowledge; the interaction of both is necessary.

The Gf refers to the biological ability to flexibly adapt and deal with new situations based on the ability to classify, relate and use so-called operational memory. It is linked to the evolutionary process at its peak in adolescence and decreases in old age. Crystallized intelligence depends on the subject's experience in the cultural environment. Both are necessary for reading and math learning when presented

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orally, as numerical series, and can be a predictor of school performance. The test was applied by 2 expert psychologists with no previous knowledge of the F data, so as to avoid bias. Each participant's performance (IQ value) was classified into categories: Very superior: >129; Superior: 120–129; Average high: 110–119; Average: 90–109; Average low: 80–89; Border: 70–79; Extremely low: <70[28]. The result from each participant was converted to percentile according to their age.

Regarding statistical analysis, first, we examined the univariate (mean, standard deviation, and proportions) characteristics of demographics. The variables, concentration of F in tap water, F in urine, and IQ were log10-transformed and reported as Geometric Mean (GM) and Standard Error (SE).

The relationship between F in tap water, F in urine, and IQ were analyzed using bivariate tests as applied (correlations, t-student, ANOVA), p-value <0.05 was considered as significant. All statistical analyzes were performed using SPSS 20 (SPSS Inc., Chicago, IL, UNIÓN) and considered p <0.05 as statistically significant.

The necessary authorizations were by the principals of each school and the informed letter of consent. The present work was made in full compliance with the Declaration of Helsinki[29].

RESULTS

Regarding the type of drinking water, 64.6% of the participants reported drinking and cooking with tap water (data not shown).

Significant differences of p≤0.005 were found regarding F concentrations in drinking waters among the different municipalities (see Table 1). Whilst León and Unión have F levels within the NOM mark, the F measured in Lagos and Teocaltiche can be as high as 3.5 and 10 times that recommended by the WHO (0.7 mg/L).

Table 1. Fluoride in drinking water, fluoride in urine, and score on IQ Beta III tests (GM = geometric mean, SE = standard error, Min = minimum, Max = maximum)

Locality	n	Tap water F mg/L GM ± SE (Min-Max)	Urine F mg/L GM ± SE (Min-Max)	IQ GM ± SE (Min-Max)
Lagos	444	2.8 ± 1.9*†‡ (0.5–12.3)	2.1 ± 1.4†‡ (0.05–14)	83 ± 2*†‡ (67–109)
Teocaltiche	126	6.4 ± 0.7*§‖ (1.0–7.9)	2.06 ± 1.0§‖ (1.5–31)	80 ± 6*§‖ (63–79)
Unión	63	1.3 ± 0.5†§** (1.1–7.9)	1.5 ± 1.0†§** (0.3–2)	84 ± 1†§** (67–100)
León	242	1.0 ± 0.4‡§** (0.5–1.5)	0.6 ± 0.3‡‖** (0.1–7)	90 ± 1‡‖** (72–109)
ANOVA		p=0.001	p=0.001	p=0.001

The same symbols in the same column indicate significant differences, p≤0.05

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Thus, there is a difference of 6 points between León and Unión, 7 points between León and Lagos, and 10 points between León and Teocaltiche. These differences are statistically significant $p \leq 0.005$. Also, whilst the score obtained by the León population sits within the normal average level, Unión, Lagos, and Teocaltiche's IQs sit within the low average rank. Note that, among the 1100 participants from the study, no youth with an IQ greater than 109 (i.e., with an IQ greater than average) was found in any of the 4 populations evaluated. Within the different sub-tests that make up the Beta III Test, on average, low performance was observed in the speed of information processing, non-verbal reasoning, and fluent intelligence (Table 2).

Table 2. IQ score for Beta III test
(GM = geometric mean, SE = standard error, Min = minimum, Max = maximum)

Subtest	Locality			
.	León	Unión	Lagos de Moreno	Teocaltiche
1. Keys: Measures information processing	48.8 ± 1*‖** (3–19)	36.8 ± 14§** (1–19)	18.8 ± 1*‡ (3–9)	27.4 ± 1‡§‖ (1–20)
2. Incomplete figures: Evaluates the speed of information processing	45.7 ± 1*‖** (1–8.9)	34.6 ± 1§** (1–8.1)	14.48 ± 1*‡ (1–51)	24.49 ± 1‡§‖ (1–19)
3. Equal and unequal pairs: Measures verbal reasoning	48.5 ± 1.4*‖** (3.4–19)	39.3 ± 1§** (3–18)	19 ± 14*‡ (1.9–36)	28.2 ± 1‡§‖ (1.9–19)
4. Matrices: Assesses non-verbal reasoning	48 ± 1*‖** (1–57)	36.2 ± 1.16§** (1–12)	16.8 ± 1*‡ (1–100)	25.7 ± 1‡§‖ (1–63)
5. Wrong objects: Measures fluid intelligence	48.5 ± 1*‖** (3–17)	36.6 ± 1§†** (2–14)	17.2 ± 1*†‡ (1–32)	25.6 ± 1‡§‖ (1–15)

The same symbols in the same column indicate significant differences, $p \leq 0.05$

Pearson's correlation coefficients among IQ, F in water and F in urine are shown in (Table 3).

Table 3. Pearson correlation between IQ and F

	F -tap water	IQ
F urine, Pearson correlation	0.329*	–0.323*
IQ, Pearson correlation	–0.284*	

* indicates a significant correlation between variables.

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DISCUSSION

In the present investigation, statistically significant differences were found between the different municipalities analyzed. Among these, León (average IQ 90) and Teocaltiche (average IQ 80) stand out with a difference of 10 points in the IQ test, these being the municipalities with the lowest and highest F concentrations in drinking water, respectively.

It has been reported that as the concentration of F in drinking water increases, the intelligence index decreases[20,27,30]. Data showed a positive correlation is obtained between F concentration in water and urine, and a negative correlation is obtained between F concentration in urine and IQ scores. Thus evidencing that the highest exposure to F correlates with lower IQ scores. Besides, the fact that no participant scored higher than 109 is alarming, given that for the academic level that the participants are into, this would not be as expected. Although decreased intellectual ability is known to be the result of a wide variety of factors (innate and acquired), this study was carried out taking into account similar environmental factors such as educational level and parental occupation, life habits, and social customs (data not revealed), thus reinforcing the effect of F levels in the brain and cerebral activity, since it has been reported that the intake of F from 2 mg/L alters the biochemistry and morphology of the brain[1]. In this sense, this research can be taken as a new piece of evidence that the excessive intake of F levels from childhood decreases the mental work capacity which is carried throughout adult life.

The tasks that were under performed from the Beta III Test are those requiring more time to integrate the information, including sequential processing of information, discrimination of visual information, attention-to-detail, and/or detection of spatial relationships. All these processes are extremely necessary for the acquisition and understanding of reading and writing, as well as in solving logical-mathematical problems. Having these intellectual afflictions can lead to fewer opportunities to obtain a better-paid job and thus can have an impact on the quality of life of these individuals.

Because in Mexico it is estimated that approximately 14 million people live in places where high levels of F prevail, and of which 52%[31,32] to 82%[26] already have some degree of dental fluorosis (an early symptom of toxicity caused by F[30,33]); this problem should not be overlooked.

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