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ORIGINAL PAPER

Correlation of lithium levels between drinking water obtained from different sources and scalp hair samples of adult male subjects

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Abstract There is some evidence that natural levels of lithium (Li) in drinking water may have a protective effect on neurological health. In present study, we evaluate the Li levels in drinking water of different origin and bottled mineral water. To evaluate the association between lithium levels in drinking water with human health, the scalp hair samples of male subjects (25–45 years) consumed drinking water obtained from ground water (GW), municipal treated water (MTW) and bottled mineral water (BMW) from rural and urban areas of Sindh, Pakistan were selected. The water samples were pre-concentrated five to tenfold at 60 °C using temperature-controlled electric hot plate. While scalp hair samples were oxidized by acid in a microwave oven, prior to determined by flame atomic absorption spectrometry. The Li content in different types of drinking water, GW, MTW and BMW was found in the range of 5.12–22.6, 4.2–16.7 and 0.0–16.3 µg/L, respectively. It was observed that Li concentration in the scalp hair samples of adult males consuming ground water was found to be higher, ranged as 292–393 µg/kg, than those who are drinking municipal treated and bottle mineral water (212–268 and 145–208 µg/kg), respectively.

Keywords Lithium · Scalp hair · Adult males · Drinking water · Atomic absorption spectrophotometer

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Introduction

Lithium (Li) is a newly recognized nutritionally essential trace element, and it was studied the existence of statistically significant inverse associations of its levels in drinking water with mentally sickness (Schrauzer 2002; Schopfer and Schrauzer 2011). Although the Li is widely used at pharmacological dosages in the treatment of various mental disorders (Arancibia et al. 2003), its effects at normal nutritional levels have not yet received much attention. A substantial body of the literature supports the role of lithium in neuroprotection, neurorepair and neurogenesis throughout the lifespan (Mischley 2012; Barr et al. 1993; Licht 2012).

The association between Li content in drinking water and mental health is immensely investigated (Helbich et al. 2012; Stefansson et al. 2007; Helbich et al. 2013). It has still remained of interest in medical treatment of Alzheimer', Parkinson's, Huntington's diseases, as therapeutic and neuroprotective (Gallicchio 2011; Rapoport et al. 2009; Rybakowski 2011). The positive effects of Li on mood and mental health were first described in the late 1940s (Bluml et al. 2013). The Li is a nutritionally trace element predominantly found in drinking water in a wide range of concentration 0.06–5460 μg/L, with a median value of 4.8 μg/L (Concha et al. 2010; Heghedus-Mindru et al. 2008; Krachler and Shotyk 2009).

Some epidemiological studies suggest that intake of Li levels even in trace levels via drinking water may have anti-suicidal effect and promote longevity (Baldessarini et al. 2006; Cipriani et al. 2005; Ohgami et al. 2009; Terao et al. 2009; Zarse et al. 2011). There is growing evidence from ecological studies that trace levels of Li in drinking water may protect against suicide (Terao et al. 2009; Zarse et al. 2011). This element is also a central nervous system depressant at higher doses, although the mechanisms and dose ranges have yet to be elucidated (Mischley 2012). Several studies have investigated the relationship between the naturally occurring Li content in drinking water and suicide mortality (Schrauzer 2002; Ohgami et al. 2009; Kabacs et al. 2011; Kapusta et al. 2011). A negative association between Li concentrations in the municipal water supply and suicide rates was first time reported for 27 Texas counties (Ohgami et al. 2009). It was reported that the long-term Li therapy and elevated concentration in drinking water may create adverse side effects include thyroid abnormalities and renal tubular damage (Aral and Vecchio-Sadus 2008; Broberg et al. 2011).

Due to biological impact of Li, it becomes important to hold the information on its content in drinking water obtained from different sources. The emphasis made, especially on bottled mineral water consumed vastly everywhere, especially in big cities. The analytical methods for Li determination are flame atomic emission spectrometry and flame atomic absorption spectrometry (Aliasgharpour and Hagani 2009; Hernandez et al. 2005; Stecka and Pohl 2011).

The aim of present study was to evaluate the levels of Li in drinking water obtained from ground, municipally treated and bottled mineral water, consumed by the population of rural and urban areas of Sindh, Pakistan. Simultaneously scalp hair samples of adult males were also collected based on consuming different types of drinking water. The Li was determined in scalp hair, after acid digestion prior to determined by flame atomic absorption spectrometry (FAAS). The large dataset obtained for Li levels was subjected to cluster analysis, a multivariate technique to evaluate information about the similarities and dissimilarities present among the different types of drinking water.

Experimental work

Apparatus

WTW 740 Germany pH meters were employed for pH measurements of the reagents and water. Atomic absorption spectrometer of Hitachi Ltd., Model 180-50 and S.N. 5721-2 with a deuterium lamp back corrector equipped with a 10-cm burner head. Hitachi Model 056 recorder was used for recording analytical data of the elements under investigation. The single-element hollow cathode lamp was used as radiation sources, at wavelength of 670.8 nm and 10 mA current. For flame mode, oxidant (air) 1.6 kg/cm^2 and fuel (acetylene) 0.25 kg/cm^2 were used.

Sampling

Water sampling

The groundwater samples (hand pump) at the depth >15 m ($n = 100$) were collected from different rural areas of Sindh, Pakistan in 2014 with the help of a global positioning system. The municipal treated drinking water samples ($n = 120$) were collected from different rural and urban areas of Sindh, Pakistan. The areas, from where, we collected water samples are shown in Fig. 1. The collected water samples were kept in well-stoppered polyethylene plastic bottles, which were previously soaked in 10 % nitric acid for 24 h and rinsed with ultrapure water obtained from ELGA Lab Water system. The 25 different bottled mineral water samples of different

Fig. 1 Map of Pakistan with Sindh Province. *Shaded part* shows the approximate locations of water sampling

brands packed on four different dates (five samples of each brand) were collected from local market of Pakistan. On arrival to laboratory, the BMW were stored at −20 °C till further analysis. All water samples were stored in an insulated cooler containing ice and delivered on the same day to the laboratory and were kept at 4 °C until processing and analysis.

Scalp hair sampling

Scalp hair (hair) of male subjects ($n = 375$) were simultaneously collected with water samples from different rural and urban areas of Sindh, Pakistan and those consumed only bottled mineral water. The study subjects were divided into three groups based on consuming different types of drinking water, ground ($n = 130$), municipal treated ($n = 120$) and bottled mineral water ($n = 125$). The persons who gave their consent were recruited for biological sample collection. According to our semistructured interview, the selected subjects confirm that they consumed water of different regions for last five years, while none of the participants had psychiatric illnesses. The each participant was informed about the aim of study in local language (Sindhi and Urdu) through a consent form using a formatted questionnaire to obtain verbal and written information. Information including demographic and lifestyle characteristics such as smoking, duration of living in understudy areas, sources of drinking water was collected.

The hair samples were collected from the nape of the neck using stainless steel scissors. The hair were sealed separately in labeled polyethylene ziplock bags and not opened until return to the laboratory. Prior to analysis, all hair samples were cut into small pieces (2 cm). The washing procedure carried out was that proposed by the International Atomic Energy Agency. Thus, hair samples were first washed with ultrapure water and then three times with acetone and finally with ultrapure water (three times). The samples were then oven dried at 60 °C.

Analytical procedure

The physicochemical parameters of all collected water samples carried out in laboratory following the standard protocols (APHA 1998). Water quality parameters, their units, abbreviations and methods of analysis are summarized in Table 1. The pH, electrical conductivity (EC), total dissolved solids (TDS) and salinity of each water sample were measured at the sampling points by digital pH and EC meters, respectively. The analytical data quality was ensured through careful standardization, procedural blank measurements and duplicate of each sample. For Li analyses, water samples were concentrated five to ten times by evaporated water samples at 60 °C on an electric hot plate, filtered and kept at 4 °C until further analysis.

Microwave-assisted acid digestion method

Duplicate dried hair samples of each subject were directly taken into Teflon PTFE flasks. Two milliliters of a freshly prepared mixture of concentrated HNO_3–H_2O_2 (2:1 v/v) was added to each flask and kept for 10 min at room temperature. Then, placed the flasks in covered PTFE container and heated in microwave oven at 80 % of total power (900 W), for 2–10 min. It was observed that 4 min required for complete oxidation of hair matrix. After cooling, the digestion flasks were cooled, and resulting solution was evaporated to semidried mass to remove excess acid and then diluted to 5.0 ml in volumetric flasks with 0.1 mol/L of nitric acid. Duplicate blanks (without sample) were carried through the complete procedure. The concentrations were obtained directly from calibration graphs after correction of the absorbance obtained from reagent blank. The validity and efficiency of the procedure were checked with certified reference materials of NCS DC 73347 human hair and SRM 1643e water as well as standard addition method at two concentration levels in real water and hair samples.

Statistical analysis

All statistical analyses were performed using the computer program Excel (Microsoft Corp., Redmond, WA, USA) and Minitab 13.2 (Minitab Inc., State College, PA, USA). The results of the water samples collected from different origin and scalp hair samples are reported as mean values with standard deviation (SD). The distribution of the data of Li in different water and scalp hair samples was checked by the Shapiro–Wilk test for normality. Possible associations between Li levels in drinking water of different origin and scalp hair samples of male subjects were explored by Spearman's correlation analysis. Nonparametric Mann–Whitney *U* tests were applied to test for significant differences in metal concentrations between urban and rural population. All relationships were significant at 95 % confidence interval ($p < 0.05$), unless otherwise noted.

Analytical figure of merit

The linear range of calibration curve reached from the detection limit up to 500 µg/L for Li. The limit of detection (LOD) was defined as 3 s/m, where s is the standard deviation corresponding to 10 blank injections, and m is the slope of the calibration graph. The LOD and LOQ of 0.38 and 1.2 µg/L were calculated for Li, respectively. The validity and efficiency of the methods were also checked by certified reference materials of NCS DC 73347 human hair and SRM 1643e water as well as standard addition method in a

Table 1 Water quality parameters associated with their abbreviations, units and analytical methods used

Variables	Abbreviations	Units	Analytical methods
pH	pH	pH unit	pH meter
Electrical conductivity	EC	mS/cm	Electrometric
Salinity	Salinity	%	Electrometric
Total dissolved solids	TDS	mg/L	Gravimetric
Lithium	Li	µg/L	FAAS

Table 2 Lithium concentration in certified reference materials of water and human hair

Certified value	Experimental value	%Recovery	$t_{tabulated}$
NCS DC 73347 human hair (μg/g)			
2 ± 0.1	1.98 ± 0.07	99.0	0.519
SRM 1643e water (μg/kg)			
17.0 ± 1.7	16.8 ± 0.9	98.2	0.665

Sample/added standard of Li μg/L	Experimental values	%Recovery	Paired t test[a] $t_{Experimental}$
Validation of Li analysis by standard addition method in real samples of water and scalp hair			
GW	6.4 ± 0.4	–	
10	16.2 ± 0.9	98.8	0.285
20	26.1 ± 1.0	98.9	0.276
Scalp hair μg/Kg			
Scalp hair	301 ± 26	–	
100	398 ± 28	99.2	0.265
200	496 ± 32	99.0	0.285

$t_{Critical}$ at 95 % CI = 2.57 at degree of freedom 5 = (n − 1)

[a] Paired t test between standard addition in real samples and experimental values

real water and scalp hair sample (Table 2). The precision of the methodologies was expressed as the percent of coefficient of variation (%CV) calculated as <5 %.

Results

The goal of this study was to analyze the drinking water samples of different origins: groundwater, municipal treated and bottled mineral water samples as well as effects on general population (male 25–45 years). For this purpose, scalp hair samples were collected from male subjects consumed water of different origins for >5 years.

The physicochemical parameters of water samples (pH, electrical conductivity, total dissolved solids and salinity) of all three types of drinking water are presented in Table 3, and the results are compared with the values of World Health recommended limits (WHO 2004). Table 3 shows that the pH of drinking water samples of GW, MTW and BMW ranged as 6.78–8.20, 6.59–8.02 and 7.01–8.36, respectively, indicates that water of different origins were slightly acidic to alkaline in nature but within the WHO recommended values (WHO 2004). The mean values of salinity, conductivity and total dissolved solids were found to be higher in GW than MTW, which are consisted with other study (Arain et al. 2008).

The mean values of Li with standard deviation of drinking water obtained from different sources (GW, MTW and BMW), and scalp hair samples are shown in Table 4. The Li levels in the GW, MTW and BMW were observed in the range of 5.12–22.6, 4.18–16.7 and 0.0–16.3 μg/L, respectively. Among 25 BMW of different brands, about 25 % have <LOD. The levels of Li in scalp hair of three study groups consumed GW, MTW and BMW were calculated as median at 95 % confidence interval (CI) 328 [CI: 322, 350], 245 [CI: 234, 251] and 158 [CI: 153, 174] μg/kg, respectively. It was observed that the level of Li was significantly higher in those adult males who consumed GW and MTW than normal values (9–229 μg/Kg) reported by Schrauzer (2002), whereas the study subjects consuming BMW have lower levels than normal values.

The multivariate technique, cluster analysis (CA) can be applied of resulted data of water samples of different origins, to know the difference and similarity among them (Danielsson et al. 1999). Levels of similarity at which observations are merged, used to construct a dendogram (Chen et al. 2007). The result of CA based on the level of Li in drinking water obtained from GW, MTW and BMW samples consumed by different communities (rural, urban and upper class), respectively, as shown in Fig. 2. The dendogram clarifies the dissimilarity in Li levels between GW and other two types of drinking water (MTW and BMW). The data on Fig. 2 indicate that ground water contains high levels of Li and it may provide sufficient amount of this element to consumers. The CA technique is helpful in assessing Li levels and other quality parameters of drinking water obtained from different sources (rural and urban areas) and also for sampling network. The same aspect is also reported by other researchers (Kazi et al. 2009; Kim et al. 2005; Simeonov et al. 2004).

Regression analyses have been carried out between the Li concentrations in scalp hair samples of study population consuming drinking water of different origins. The linear regressions showed correlation (r) between the Li concentrations in drinking water obtained from GW water versus scalp hair samples of

Table 3 Physicochemical parameters of groundwater (GW), municipal treated water (MTW) and bottled mineral water (BMW)

Parameter	WHO limits	GW ($n = 100$)	MTW ($n = 120$)	BMW ($n = 25$)
pH	6.5−8.5	7.47 ± 0.35	7.25 ± 0.44	7.68 ± 0.08
EC (mS/cm)	0.25	1.61 ± 0.09	1.15 ± 0.1	0.49 ± 0.03
TDS (mg/L)	1000	801 ± 24	624 ± 21	224 ± 5
Salinity(mg/L)	–	0.88 ± 0.16	0.44 ± 0.1	0

Table 4 Lithium concentration in ground, municipal treated, bottled mineral water samples and scalp hair samples of adults of different areas

Types of water	Lithium (µg/L)	Scalp hair samples (µg/Kg)
Ground water	10.6 ± 1.9	336 ± 35
Municipal treated water	7.49 ± 3.5	243 ± 17
Bottled mineral water	9.04 ± 0.7	164 ± 19

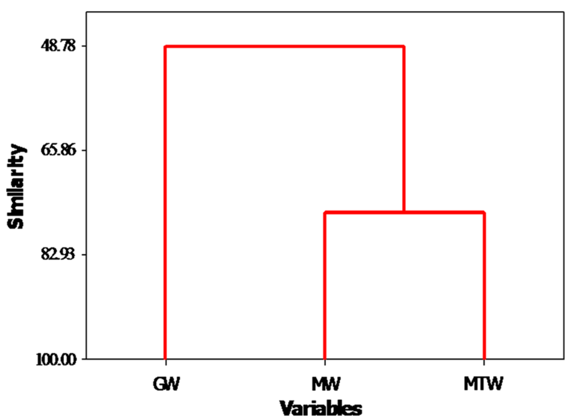

Fig. 2 Dendogram for cluster analysis based on similarity of Li levels in water samples of different origins

Table 5 Linear Regression and Pearson's coefficient for lithium concentrations in scalp hair samples of adults referent of urban areas versus lithium concentration in drinking water

SH[a] versus GW[b]	SH versus MTW[c]	SH versus BMW[d]
5.14x + 270	2.10x − 260	2.32x + 148
$r = 0.731$	$r = 0.649$	$r = 0.535$

[a] Scalp hair
[b] Groundwater
[c] Municipal treated water
[d] Bottled mineral water

adults male was higher ($r = 0.731$) (Table 5) than those values obtained for MTW and BMW versus scalp hair ($r = 0.649$ and 0.535), respectively ($p < 0.01$).

Discussion

In present study, we evaluated the effect of lithium intake via different types of drinking water (GW, MTW and BMW) in adult males, residents of rural and urban areas of Sindh, Pakistan. The GW samples mostly collected from rural areas, while MTW samples were collected from urban areas of Sindh, Pakistan. The GW and MTW were mostly used as the sole source for drinking and domestic purposes in urban and rural areas. The BMW production is distributed all over the main cities of Pakistan, and its sampling has covered important productive areas/socioeconomic factor. The different types of drinking water used had statistically significant differences in their physicochemical parameters while all the studied water samples were consisted for the pH values, which were within the permissible limit. The electric conductivity, TDS and salinity were present in decreasing orders as GW > MTW > BMW. However, all these values were within the WHO permissible limit.

Table 6 Comparison of Lithium contents in water μg/L and scalp hair (μg/g) of people from various parts of the world

Water			
Author/year	Type of water	Concentration (μg/L)	Countries
Ohgami et al. (2009)	Tap water	0.7–59	Japan
Schrauzer and Shrestha (1990)	Tap water	High (70–160), Moderate (13–60), Low (0–12)	27 counties in Texas USA
Kabacs et al. (2011)	Water	<1–21	England
Giotakos et al. (2013)	Public water	11.1 (0.1 to 121)	Greece
Concha et al. (2010)	Water	≥1000	Northwestern Argentina
Figueroa et al. (2012)	Surface water	Average > 100–5000	North of Chile[a]

Reference	Age group years	Genders	Mean ± SD (μg/kg)
Hair samples			
Schopfer and Schrauzer (2011)	1–84	Male	19 ± 25
	1–87	Female	27.5 ± 29
Luo et al. (2014)	20–98	–	100
Marlowe et al. (1983)	9.43 ± 2.81	Control group	230 ± 350
	11.62 ± 3.06	Mentally retarded group	260 ± 580
Figueroa et al. (2014)	5–70	Control group[a]	Average 5300
Blaurock-Busch et al. (2012)		Autistic children	1.5

[a] Water samples and hairs of adult population living in lithium exposed area

The variation in levels of Li in water samples of different sources, which is consisted that other studies that variation might be due to geographic region and correlate with natural Li resources (Schrauzer 2002; Concha et al. 2010). The Li is also classified as an essential trace element with an RDA of 1 mg/day for adults (Schrauzer 2002). Natural Li in water was reported to have the potential to influence mental health (Cipriani et al. 2005; Altamura et al. 2011). In northern Chile, a region with one of the largest Li resources in the world is present (Kampf et al. 2005). It was reported in a study carried out in northern Argentina, that natural concentrations of Li in ground water may reach up to 5.2 mg/L, leading to a natural daily intake of Li ~10 mg/day (Schrauzer 2002). This resulted data of Li were relatively high in comparison with reported as 1.3 mg/L measured in Austria (Schrauzer 2002; Concha et al. 2010).

It was extensively studied that Li, a very effective agent for the prevention of depression, and has considerable neuroprotective effects, far more in extent and human relevance than any other psychotropic agents (Helbich et al. 2012; Zarse et al. 2011; Broberg et al. 2011; Hampel et al. 2009; Nunes et al. 2013).

The Lithium concentrations in the drinking water (groundwater, municipal treated and bottle mineral water) were close to reported values by Kabacs et al. (2011) and Giotakos et al. (2013), while almost lower than studied by Schrauzer and Shrestha (1990), Ohgami et al. (2009) and Concha et al. (2010) (Table 6). Whereas in the lithium-rich regions of northern Chile, the lithium content of the surface waters were found to be higher than average values of 5000 μg/L (Figueroa et al. 2012).

The concentrations of Li in scalp hair samples of study population belong to urban and rural areas, consuming different types of water were close to those values, reported in past study (Marlowe et al. 1983), whereas the observed values of those subjects drinking ground and municipal treated water were found to be higher than reported by Schopfer and Schrauzer (2011), Blaurock-Busch et al. (2012) and Luo et al. (2014) (Table 6). In Li-rich regions of northern Chile, the average Li level (5300; ND–9210 μg/kg) in hair samples of population was found to be significantly elevated (Figueroa et al. 2014).

Conclusion

The resulted data indicated the BMW have low levels of Li as compared to drinking water obtained from ground water (consumed by rural population) and municipal treated water as drinking sources. As the bottled mineral water consumption is based on high socioeconomic status, especially in urban areas, it is necessary for those people to take food commodities contained high level of Li content. This study also provides strong evidence that geographic regions and treatment processes are responsible for Li concentrations in drinking water. However, further research is required, especially for human to determine the amount of Li that is beneficial for their neurohealth and would assist in establishing recommended daily intake levels.

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