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Determination of essential and non-essential element contents of drinking water and baby water for infant's nutrition

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Abstract: In this study, essential (Ca, Cr, Cu, Fe, K, Mg, Na, P, Zn), and non-essential (Al, Ni, Pb) element contents of the drinking and baby water samples which are sold in the local market and tap water samples in Istanbul were examined. It was determined that elements of Cr, Cu, Fe, P, Zn, Al, and Ni were below detection limits in all water samples. Among the non-essential elements analyzed in water samples, Pb was the only detected element.

At the same time, the percentages that meet the daily element requirements of infants were also calculated. As a result of the evaluations made, there is no significant difference in infant nutrition between baby waters and other drinking waters in terms of the element content.

Keywords: baby water, essential elements, non-essential elements, element consumption

1 Introduction

The consumption of essential nutrients with adequate quantities and types is significant for the healthy growth of infants. Also, the appropriate amount of fluid intake is vital for infants because of body temperature regulation, transportation of nutrients, cell metabolism, and normal

kidney function (United States Department of Agriculture Food and Nutrition Service, 2009). Breast milk is the main fluid source for infants especially for the first six months (Ministry of Health of New Zealand, 2008). However, in some cases, infants cannot be breastfed and substitutes like infant formulas are crucial for both 0-6 months and 6-12 months old infants to get sufficient nutrients. Therefore, the ingredients and the quality of the breast milk substitute foods and water, which is mainly used for the preparation of infant formula, gain importance. Some studies investigate the elemental composition and daily intake amounts of some essential elements. Mir-Marqués et al. (2015) obtained different commercial baby foods containing meat, fish, vegetable, and fruit from the Spanish market. The mineral composition was determined for 14 elements (Al, Ba, Cd, Ca, Cr, Cu, Fe, K, Mg, Mn, Mo, Ni, Sr, Zn) and adequate mineral intake values were calculated. Silva et al. (2013) assessed the amount of particular essential elements of Fe, Zn, Cu, and Mn in baby foods to evaluate their bioaccessibility by the human body for the infants. Pandelova et al. (2012) calculated the infant intakes of some non-essential and the essential elements in the most consumed baby foods in Europe including infant formula, solid foods, and beverages (SFB).

Besides these baby foods, water consumption is very significant for baby nutrition. The drinking water may contain some elements which are known or suspected to be essential for humans. Due to the consumed water affects the total trace element and mineral intake of infants, its content should be known. The investigated water types and their element contents in some literature studies are given in Table 1.

In recent years, drinking water produced for infants and called “baby water” is consumed as well as other bottled and tap water. The nutrient properties of water are related to the consumption and affected by the behavioral factors and environmental conditions (Olivares and Uauy, 2005). The nutritionally important minerals in water are

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Table 1: Published studies about essential and non-essential element concentrations of water in literature

Water types	Essential elements (mg/L)							Non-essential elements (mg/L)				Reference	
	Ca	Cr	Cu	Fe	K	Mg	Na	P	Zn	Al	Ni		Pb
Tap water (mean)	North American	Surface water sources	34.00 ±			10.00 ±	35.00 ±						Azoulay et al., 2001
		Ground water sources	21.00 52.00 ±			80.00 20.00 ±	41.00 91.00 ±						Azoulay et al., 2001
	Riyadh	Eastern Riyadh	24.00 52.00		0	13.00	67.00 57.00			0.00784			Abed and Alwakeel, 2007
		Western Riyadh	9.60		0		11.50			0.00988			Abed and Alwakeel, 2007
		Central Riyadh	39.50		0		26.00			0.00419			Abed and Alwakeel, 2007
	Peninsular Malaysia		6.65 ±	0.04 ±	0.06 ±	1.10 ±	4.30 ±		0.04 ±		0.91 ±	0.28 ±	Azrina et al., 2011
			5.30	0.18	0.06	1.61	3.39		0.07		0.56	0.86	
Bottled water (mean)	Riyadh	A	8.40		0.02	1.00	22.40			0.006			Abed and Alwakeel, 2007
		B	17.00		0.02	2.50	14.00			0.011			Abed and Alwakeel, 2007
		C	17.00		0	7.00	20.00			0.010			Abed and Alwakeel, 2007
	North American	Spring waters	18.00 ±			8.00 ±	4.00 ±						Azoulay et al., 2001
		Mineral waters	22.00 100.00 ±			18.00 24.00 ±	4.00 371.00 ±						Azoulay et al., 2001
		Low mineralization water	125.00 60.00 ±			42.00 16.00 ±	335.00 13.00 ±						Azoulay et al., 2001
		Moderate mineralization water	40.00 262.00 ±			19.00 64.00 ±	13.00 157.00 ±						Azoulay et al., 2001
		High mineralization water	139.00 60.00 ±			37.00 16.00 ±	797.00 1.51 ±						Azoulay et al., 2001
			59.00			20.00	153.00						

selenium (Se), sodium (Na), fluorine (F), potassium (K), molybdenum (Mo), boron (B), magnesium (Mg), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), and chromium (Cr). The lack or excess of these elements may cause adverse influences on the infant's body (Molska *et al.*, 2014).

In spite of the fact that there are lots of studies about the element content of baby food such as infant formulas and fruit juices, there was no study about the element content of baby waters and comparison with drinking waters and tap water. The purpose of this study is the determination and comparison the element content of baby, drinking, and tap water samples. Also, it is aimed to calculate the daily main intake (DMI) of analyzed elements in water samples for both 1-6 months and 6-12 months old infants. Additionally, the obtained DMI values are compared with the element requirements of infants depend on their gender and weight.

2 Results and discussion

2.1 Validation of analytical method

Table 2 shows the results of analytical method validation in terms of detection and quantification limits, correlation coefficients, and coefficient of variance measurements by ICP-OES. R^2 of the calibration curves for these elements were higher than 0.999.

The stability of the detector response was investigated by analyzing a multi-element Standard solution with moderate concentration with each batch (ten samples). The relative standard deviation and the values of CV% were less than 10% for all the analyte elements.

2.2 Instrumental analysis results

The concentrations of essential and non-essential elements in samples are given in Table 3. Essential elements of Ca, K, Mg, Na, and non-essential elements of Pb were found in all water types with different concentrations. On the other hand, Cr, Cu, Fe, P, Zn, Al, and Ni were below the detection limit in all samples.

Ca concentrations varied between 9.067-32.125 mg/L for baby water, 4.710-13.765 mg/L for drinking water. However, for city water, Ca content was measured as 1.931 mg/L which was the lowest Ca in analyzed samples. When water samples were examined, it was seen that baby

Table 2: Validation of analytical method obtained using a Standard reference in terms of limits of detection and quantification

Element	Limits of detection (mg/L)	Limits of quantification (mg/L)	Correlation coefficient (R^2)	Coefficient of variance (CV%)							
				BW-1	BW-2	BW-3	DW-1	DW-2	DW-3	DW-4	CW-1
Ca	0.0063	0.0209	0.9999	9.575	1.957	1.068	2.517	9.621	8.189	2.372	0.329
Cr	0.0001	0.0005	0.9996	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Cu	0.0004	0.0013	0.9999	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Fe	0.0017	0.0055	0.9999	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
K	0.0015	0.0049	0.9999	2.175	0.288	2.886	8.529	2.323	7.644	3.885	0.078
Mg	0.0010	0.0035	0.9999	3.550	0.161	0.041	0.059	1.204	1.433	2.816	0.177
Na	0.0029	0.0096	0.9999	8.033	0.893	5.936	1.575	2.706	0.766	1.013	0.413
P	0.0038	0.0125	0.9998	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Zn	0.0002	0.0006	0.9996	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Al	0.002	0.0069	0.9997	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Ni	0.0008	0.0028	0.9999	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Pb	0.0018	0.006	0.9996	2.244	8.838	9.428	2.571	8.318	7.856	7.443	8.658

*b.d.l: below detection limit.

Table 3: The concentrations of essential and non-essential elements in water samples

Elements	Conc. (mg/L)	BW-1	BW-2	BW-3	DW-1	DW-2	DW-3	DW-4	CW-1
Essential	Ca	32.125	9.067	19.195	13.765	12.170	11.570	4.710	1.931
	Cr	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
	Cu	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
	Fe	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
	K	0.13	0.246	0.074	0.987	0.487	0.037	0.182	0.181
	Mg	14.34	1.762	5.130	2.359	2.759	1.924	1.030	0.398
	Na	1.426	1.425	0.203	1.212	0.706	1.844	2.093	1.197
	P	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Non-essential	Zn	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
	Al	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
	Ni	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
	Pb	0.0315	0.016	0.030	0.028	0.009	0.018	0.014	0.025

* b.d.l: below detection limit.

waters, except BW-2, had higher Ca content than drinking and city water samples.

The concentration of K in the samples shows an irregular change. The lowest and highest values were observed for DW-3 (0.037 mg/L) and DW-1 (0.987 mg/L), respectively. K concentration of other water samples was in this range.

In baby waters, Mg content of BW-1 (14.340 mg/L) and BW-3 (5.130 mg/L) showed significant difference according to the other analyzed water samples while BW-2 (1.762 mg/L) sample had a similar Mg concentration with drinking water. Mg concentration of drinking water samples changed in the range of 1.030 mg/L (DW-4) and 2.759 mg/L (DW-2). Among all samples, city water had the lowest Mg amount as 0.398 mg/L.

Na concentration of baby waters was between 0.203 mg/L (BW-3) and 1.426 mg/L (BW-1) when Na content of the drinking water samples was between 0.706 mg/L (DW-2) and 2.093 mg/L (DW-4). On the other hand, it was observed that while the concentration of other essential elements in the city water was lower than baby water and drinking water samples, Na concentration (1.197 mg/L) was in the same range as them.

The concentration of the only detected non-essential element of Pb was between 0.016 mg/L (BW-2) and 0.032 mg/L (BW-1) in baby water. In drinking water, Pb concentrations were in the range of 0.009 mg/L (DW-2) and 0.028 mg/L (DW-1). The Pb content was determined as 0.025 mg/L in the city water.

It was calculated that how many percent of the daily element requirement of the infants was met by the essential elements (Na, Ca, K, and Mg) in the analyzed waters, and the results are shown in Table 4. In calculations, water/free liquids required (WR) and adequate intakes (AI) values of the essential elements

were used. The results were estimated for both female and male infants. According to results, for 0-6 months old infants, maximum Na intake percentages were calculated as 1.3779% (DW-4) for male infants and 1.2558% (DW-4) for female infants. Maximum Ca (12.6894% for male and 11.5650% for female) and Mg (37.7620% for male and 34.4160% for female) intake percentages were found in BW-1. Maximum K intake percentages were calculated as 0.1948% and 0.1776% in DW-1 for male and female infants, respectively.

When the results of 6-12 months old infants compared with 0-6 months old infant results, it was observed that maximum intake percentages were obtained in the same water samples for all essential elements due to their higher element concentration.

In Table 5, daily main intake values of Pb based on gender and age of infants and PTDI values are presented. PTDI values were calculated for the ages of 1st, 6th, and 12th months according to the infant weights which are given in Table 6. When results were compared, it was seen that daily main intake values of Pb for each water sample were below PTDI and were not at a harmful level for the infant body. Also, it was observed that Pb concentration was not dependent on water types because it showed a difference according to brands.

3 Conclusion

In this study, essential (Ca, Cr, Cu, Fe, K, Mg, Na, P, Zn), and non-essential (Al, Ni, Pb) element contents of the drinking and baby water samples which are sold in the local market and tap water samples in İstanbul were examined. According to obtained results, it was

Table 4: Daily intake percentages of essential elements with the consumption of baby water (%)

Water types	0-6 months											
	Na				Ca				K			
	Male		Female		Male		Female		Male		Female	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
BW-1	0.523	0.939	0.499	0.856	7.068	12.689	6.746	11.565	0.014	0.026	0.014	0.023
BW-2	0.523	0.938	0.499	0.855	1.995	3.581	1.904	3.264	0.027	0.049	0.026	0.044
BW-3	0.074	0.133	0.071	0.122	4.223	7.582	4.031	6.910	0.008	0.015	0.008	0.013
DW-1	0.444	0.798	0.424	0.727	3.028	5.437	2.891	4.955	0.109	0.195	0.104	0.178
DW-2	0.259	0.465	0.247	0.423	2.677	4.807	2.556	4.381	0.054	0.096	0.051	0.088
DW-3	0.676	1.214	0.645	1.106	2.545	4.570	2.430	4.165	0.004	0.007	0.004	0.007
DW-4	0.767	1.378	0.733	1.256	1.036	1.861	0.989	1.696	0.020	0.036	0.019	0.033
CW-1	0.439	0.788	0.419	0.718	0.425	0.763	0.406	0.695	0.020	0.036	0.019	0.033
Water types	6-12 months											
	Na				Ca				K			
	Male		Female		Male		Female		Male		Female	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
BW-1	0.305	0.391	0.278	0.366	9.761	12.5411	8.896	11.738	0.015	0.019	0.013	0.017
BW-2	0.304	0.391	0.277	0.366	2.755	3.5394	2.511	3.313	0.028	0.036	0.025	0.033
BW-3	0.043	0.056	0.039	0.052	5.832	7.4934	5.316	7.014	0.008	0.011	0.008	0.010
DW-1	0.259	0.332	0.236	0.311	4.182	5.3736	3.812	5.030	0.111	0.143	0.102	0.134
DW-2	0.151	0.194	0.137	0.181	3.698	4.7510	3.370	4.447	0.055	0.071	0.050	0.066
DW-3	0.394	0.506	0.359	0.474	3.516	4.5168	3.204	4.228	0.004	0.005	0.004	0.005
DW-4	0.447	0.574	0.407	0.537	1.431	1.8387	1.304	1.721	0.021	0.026	0.019	0.025
CW-1	0.256	0.328	0.233	0.307	0.587	0.7540	0.535	0.706	0.020	0.026	0.019	0.025

Table 5: Daily main intake values of Pb based on gender and age of infants

Month		1st		6th		12th	
		Males	Females	Males	Females	Males	Females
PTDI		15.714	15.000	28.214	25.714	36.786	33.929
Daily main intake (microgram)	BW-1	13.860	13.230	24.885	22.680	31.973	29.925
	BW-2	7.040	6.720	12.640	11.520	16.240	15.200
	BW-3	13.200	12.600	23.700	21.600	30.450	28.500
	DW-1	12.100	11.550	21.725	19.800	27.913	26.125
	DW-2	3.740	3.570	6.715	6.120	8.628	8.075
	DW-3	7.920	7.560	14.220	12.960	18.270	17.100
	DW-4	6.270	5.985	11.258	10.260	14.464	13.538
	CW-1	10.780	10.290	19.355	17.640	24.868	23.275

Table 6: Water/free liquids required (WR) according to ages (Fluid Requirements for Children, 2019, available at: www.articles.complexchild.com/00037.pdf/)

Age (month)	Reference weight (kg)		Water/free liquids required (WR) (mL)	
	Males	Females	Males	Females
1	4.4	4.2	440	420
2	5.3	4.9	530	490
3	6.0	5.5	600	550
4	6.7	6.1	670	610
5	7.3	6.7	730	670
6	7.9	7.2	790	720
7	8.4	7.7	840	770
8	8.9	8.1	890	810
9	9.3	8.5	930	850
10	9.7	8.9	970	890
11	10.0	9.2	1000	920
12	10.3	9.5	1015	950

determined that elements of Cr, Cu, Fe, P, Zn, Al, and Ni were below detection limits in all water samples. The highest element concentration belonged to Ca in the samples and it was followed by Mg, Na, and K respectively. Among the non-essential elements analyzed in water samples, Pb is the only detected element. When baby waters, drinking waters, and tap water were investigated separately, it was seen that the content of the elements varied according to the water brands, not to the water types. For this reason, there is no clear distinction between the elemental contents of baby waters and drinking waters. In the study, when filtered tap water was analyzed as a control sample, it was observed that the content of Ca and K in packaged water was higher

than tap water, but there was no significant difference in other elements in this comparison. At the same time, the percentages that meet the daily element requirements of infants were also calculated. When the results are examined, it was determined that the percentage of meeting daily requirements varies depending on the concentrations changes of the elements in a different brand of baby and drinking water. As a result of the evaluations made, it was ascertained that there is no significant difference for infant nutrition between baby waters and other drinking waters in terms of the element content. This study presents a new result for conscious consumption and infant health. Waters to be used by consumers should be categorized on a reliable brand basis, not an infant, drinking or tap water as they are on the market.

Experimental

Preparation and supply of water samples

Three brands of baby water (BW) and four brands of drinking water (DW) samples were purchased from the local market in Turkey in August 2017. The waters were stored at ambient conditions (temperature, $24 \pm 5^\circ\text{C}$; humidity, $45 \pm 10\%$) in the original packings: 1 L (Brand 1-BW 1), 330 mL (Brand 2-BW 2), and 200 mL (Brand 3-BW 3) plastic bottle for baby water; 500 mL plastic bottle for drinking water.

The samples were used in the study for the determination of Na, Ca, K, Mg, Fe, Zn, P, Cu, Cr, Pb, Al, and Ni elements by Inductively coupled plasma optical

Table 7: Adequate intakes (AI) and provisional tolerable daily intake (PTDI) of elements

Element type	Element	Life stage (month)	Limits		Reference
			AI (mg/day)	PTDI (µg/kg bw)	
Non-essential	Pb	0 to 6 6 to 12		3.57	Ihedioha et al., 2016
Essential	Na	0 to 6	120		National Academies of Sciences, Engineering, and Medicine, 1998
		6 to 12	370		
	Ca	0 to 6	200		National Academies of Sciences, Engineering, and Medicine, 1998
		6 to 12	260		
	K	0 to 6	400		National Academies of Sciences, Engineering, and Medicine, 1998
		6 to 12	700		
	Mg	0 to 6	30		National Academies of Sciences, Engineering, and Medicine, 1998
		6 to 12	75		

emission spectrometry (ICP OES). In addition to the supplied waters, the city water (CW) that was purified using the Rainbow Water Filter System was also analysed. No pre-treatment process was applied to the samples before ICP-OES analysis.

Preparation of the calibration sets

Standard solutions for measuring the elements Ca, Cr, Cu, Fe, K, Mg, Na, P, Zn, Al, Ni, and Pb by ICP-OES were prepared from mono-elemental stock solutions of 1000 mg L⁻¹ (Merck, Darmstadt, Germany). Standard solutions were prepared in different concentrations by stock solutions diluted with Nitric acid 3‰ (v/v) (HNO₃, 65%) (Merck chemicals (Merck KGaA, Darmstadt, Germany)) to ensure that the water samples were compatible with the elemental amounts.

A linear calibration algorithm analysis was used to check linearity in terms of correlation coefficients (R²) for all elements. All analyses were performed in three replicates.

Elemental analysis of the water samples

Elemental analysis of water samples was performed with Perkin-Elmer Optima 2100 DV ICP-OES equipped with an AS-93 autosampler (PerkinElmer, CT, USA).

ICP-OES is a rapid and accurate elemental analysis technique for the determination and identification of minor and major elements. ICP-OES has lots of advantages in comparison to other spectral techniques. It provides high sensitivity for detecting and simultaneous

determinations of several major and minor elements (Stojanovic et al., 2014).

The measurement conditions of these analyses were determined as follows a power of 1.45 kW, plasma flow of 15.0 L min⁻¹, auxiliary flow of 0.8 L min⁻¹, and nebulizer flow of 1 L min⁻¹.

Based on the types on the market, the bottled waters were classified as follows: BW-1, BW-2, and BW-3 are baby waters, DW-1, DW-2, DW-3, and DW-4 are drinking waters. The city water was classified as CW-1.

Daily essential element intake percentages

Essential element intake percentages for infants between the months of 1-6 and 6-12 were calculated according to Eqs. 1 and 2:

$$m = C \times WR \quad (1)$$

$$DMI = m \times 100 / AI \quad (2)$$

where m is the element contents (mg) which is calculated according to water/free liquids requirement (WR) of infant based on their ages and gender (Table 2), C (mg/L) is the element concentration of water, AI is adequate intake values which are given in Table 3, and DMI is daily main intakes. Daily intake percentage (DIP) was also calculated using Eq. 3:

$$DIP = DMI \times 100 / AI \quad (3)$$

Babies have a bigger surface area to weight ratio when compared to adults and developmental levels are different. These are the parameters that cause the fluid

requirement of babies to differ from adults. In literature studies, it is seen that fluid requirements differ according to the expenditure which is proportional to the surface area. The Holliday-Segar formula is one of the various formulas used to calculate the liquid needs of infants and calculates liquid requirements based on weight.

According to this method an infant needs (Fluids and Electrolyte Management, 2019, available at: www.reliasmedia.com/articles/137306-fluids-and-electrolyte-management-part---fluids-dehydration-and-sodium-homeostasis/):

- 100 mL/kg/d for the first 10 kg of weight,
- 50 mL/kg/d for the second 10 kg of weight,
- 20 mL/kg/d for babies over 20 kg of weight.

Statistical analysis

Regression analysis was conducted using triplicate measurements of all samples and Statistica 8.0 computer programme (StatSoft Inc., Tulsa, USA) was used for the analysis. Analysis was performed for calculating average values and standard deviations of measurements.

The average values of the triplicate measurements for each sample were calculated using Eq. 4:

$$\bar{x} = \sum_{i=0}^i \left(\frac{x_i}{n} \right) \quad (4)$$

The standard deviation of the analysis results were calculated using Eq. 5:

$$s = \sqrt{\frac{\sum_{i=0}^i (x_i - \bar{x})^2}{n-1}} \quad (5)$$

where $\bar{x}$ is the average value of the sample, x_i is the average value of the sample at the parallel i , n is the number of parallel samples, and s is the standard deviation.

Quality control

Limits of detection (LOD) and limits of quantification (LOQ) and relative standard deviations are used as validation parameters for analytical analysis methods. Replicate measurements of standard or sample solutions give information about results accuracy. In this study, detection limits of all elements used in the experiment

were determined and the capability of the method according to validation results were calculated by replicate measurements results.

LOD and LOQ values were calculated from the results obtained by three and ten times the standard deviation results of the ten blank solutions (Khan et al., 2013). Solutions were prepared individually.

Percent coefficients of variance (CV%) are obtained by measuring the relative standard deviation of ten repeated replicates of one sample and it gives information about the precision of analysis. Relative standard deviations of analytical results below 15% are regarded as appropriate in terms of precision (Madeja et al., 2014).

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