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ScienceDirect
Microchemical Journal 85 (2007) 157–163
MICROCHEMICAL JOURNAL
www.elsevier.com/locate/microc

Determination of iodine in human brain by epithermal and radiochemical neutron activation analysis

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Received 5 January 2006; received in revised form 9 March 2006; accepted 9 March 2006
Available online 27 April 2006

Abstract

Despite the role of iodine for proper development of the brain and the functions of the element, the accurate data on its concentration in brain tissue are largely lacking, the main reason being analytical difficulties associated with determination of the element especially at low levels. In this work, samples from human brain regions from Hungarian patients were analyzed using epithermal and radiochemical neutron activation analysis (ENAA and RNAA, respectively). The RNAA procedure is based on alkaline–oxidative fusion followed by extraction of elemental iodine in chloroform. The results were checked by the analysis of biological standard reference materials, namely bovine liver, bone meal and diet, and by comparison with previous results obtained by a different RNAA procedure.

Keywords: Iodine; Human brain; RNAA

1. Introduction

Trace elements are required in small concentrations as essential compound of biological enzyme systems or of structural portion of biologically active constituents. The effects of trace elements are related to concentration and recorded observation range from a deficiency state, to function as biologically essential components, to an unbalance when excess of one element interferes with the function of another, to pharmacologically active concentrations, and finally to toxic and even life-threatening concentrations.

The biological role of iodine, especially in the synthesis of thyroid hormones which regulate a wide variety of physiological processes in living organism, has been known for a long time [1,2]. In all vertebrates including man, a constant supply of these hormones is necessary for proper development of the brain and for body growth as well as to keep the level of basal metabolisms and functional activity of most organs normal. The major part of this element enters living organisms via the food chain. Therefore there is considerable interest in determining the iodine content of human food and diets [2,3,4]. When the recommended dietary allowances are not met in a given population, a series of functional and developmental abnormalities occur including thyroid function abnormalities [5]. As an example, iodine in potable water from mountain region in southern Poland is very low and increased number of people with goitre and thyroid cancer has been observed there for several years [6].

When iodine deficiency is severe (i.e. iodine intake <20 μg/day), endemic goitre and cretinism occur, together with endemic mental retardation, decreased fertility rate and increased perinatal death and infant mortality. These complications are grouped under the general heading of iodine deficiency disorders (IDD) [7,8].

Newborns are particularly sensitive to the effect of both iodine deficiency and iodine excess because of the risk of thyroid impairment [9]. The excessive intake may contribute to thyroidities. Iodine intake of adults in different regions of USA (the recommended dietary allowance is 150 μg/day) and Canada (the recommended nutrient intake is 160 μg/day) have been reported to exceed the respective intake by more than six times [10]. Iodine often occurs as pollutant in terrestinal ecosystems [11]. It is expected that this pollutant will be

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doi:10.1016/j.microc.2006.03.002

reflected by increased iodine concentration in plants and this has indeed been shown in many cases [12]. High excess of iodine dose given at reactor accidents for prophylaxis as an example causes thyroid hormone blockade.

Despite the fact that iodine determination in biological tissues is of considerable importance, analytical data on its concenration in biological tissues other than thyroid are scarce, because of the complexity of solid matrices and low concentration range concerned. Although reported values for the concentration of iodine in thyroid vary widely, a value of 0.6 mg/g or a total content of 12 mg in a normal 20 g thyroid, is a reasonable value for man [2]. The value is also supported by studies employing X-ray spectrometry and direct activation analysis of living individuals [2]. Values for concentration of iodine in other organs and tissues of the body are scarce and often unreliable. Its quantitative determination requires sensitive analytical methods based on catalytic reactions, gas chromatography of iodine in the form of iodoacetone or iodo-butanone, iodide-ion selective electrodes, X-ray fluorescence spectrometry, isotope exchange and neutron activation analysis (NAA) [6,13–18]. Recently, inductively coupled plasma mass spectrometry (ICP-MS) has been developed for iodine determination in nutritional and biological reference materials and its accuracy tested by a comparison with NAA [19]. Most of the above techniques are not sufficiently sensitive for iodine determination at low levels (< 0.1 μg g^{-1}) and most of them are also not very selective and suffer from various interferences. Even the recently developed ICP-MS technique requires a careful selection of preconcentration-separation methods, depending on the matrices of biological materials, to be able to arrive at accurate results for 0.1 μg g^{-1} iodine concentrations [19]. Therefore NAA with its inherent sensitivity, selectivity and freedom from reagent blank is a technique of choice for determining iodine at even ultratrace concentrations in biological and other types of materials. Two very sensitive NAA methods for determination of traces of iodine are thermal neutron activation in either its destructive or radiochemical (RNAA) form and epithermal neutron activation analysis, so-called epithermal NAA (ENAA) for non-destructive determination of this element when its concentration is somewhat higher [20,21]. Of the various modes of NAA (RNAA) procedures employing totally post-irradiation separation, provide the lowest detection limit for the determination of iodine in biological samples. A variety of RNAA procedures have been published [4,17,18,22–24].

In our previous experiments, an RNAA procedure developed at the J. Stephan Institute, Slovenia, was employed to the determination of iodine samples of German control and Alzheimer's diseased subjects at the research reactor of Hahn–Meitner Institute, Berlin. Details of analysis have been described earlier [25]. Briefly, the irradiation was followed by a Schoniger combustion method to extract ^{128}I from brain samples. Iodine was isolated from the absorbing solution by oxidation–reduction and extraction cycles. The γ-activity of the isolated ^{128}I radionuclide was measured by a well-type HPGe detector and was compared to the activity of the irradiated KI standard solution. After γ-measurement, the chemical yield was determined by spectrophotometry for each sample individually. Results of this project has been published recently [26,27]. During these experiments it was noticed that iodine levels in a few Hungarian controls analyzed additionally were significantly higher those in German ones.

In present study we decided to analyze more brain tissues from Hungarian subjects, in order to discover whether the above findings indicate a tendency or were simply extreme cases. In addition to acquiring further data on iodine levels in the human brain tissue, which are largely missing, this could possibly lead to interesting discoveries in regional differences in the brain iodine content. In present work ENAA and RNAA procedures for iodine analysis of human brain samples developed at the Nuclear Research Institute Řež have been applied [4,24].

2. Experimental

2.1. Sample collection and standards

The brain samples were obtained from post mortem subjects who died due to accidents, cardiac infarction, etc. To establish normal concentration values all subjects were inhabitants of the urban area of Budapest and diseased for reasons not involving the nervous system. In order to form a group as homogeneous as possible, only individuals satisfying two additional basic requirements were accepted for inclusion namely those known not to have been professionally exposed during their life-time, and who were 65 or more than 65 years of age (mean age 75 years).

At autopsy, brains were removed from 13 individuals within 48–72 h after death using standard procedures [27]. All individuals showed no clinical or pathological evidence of central nervous system disease, nor were gross abnormal anatomical abnormalities found in their brain. The microscopic sections of the brains showed no significant lesions. Different regions of the brain are known to be devoted to different functions, therefore bulk analysis is not adequate. Brain were sampled at 11 different brain areas from both hemispheres (Table 1). Samples were placed in polyethylene containers (previously washed with dilute (1:1) nitric acid and deionised water) and stored at −18 °C. Instruments used for collecting tissue, storage and transportation were of the same material in all cases and care was taken to avoid contamination of samples during collection and treatment. Sample collection, sample handling and storage have been described in detail elsewhere [25]. From this collection several samples were analyzed in this work.

Table 1
Biological functions and dry to wet ratios (*D*/*W*, mean±SD) of studied brain parts

Brain region	Function	*D*/*W*, mean±SD
Nucleus caudatus	Movement (inhibition)	0.178±0.014
Putamen	Movement (inhibition)	0.203±0.011
Globus pallidus	Movement (facilitation)	0.207±0.007
Thalamus	Limbic system, emotion	0.202±0.014
Cortex frontalis parasagittalis	Cognitive function	0.171±0.018
Pulvinar thalami	Sensory system	0.200±0.010
Vermis cerebelli	Equilibrium	0.181±0.014
Gyrus hippocampus	Limbic system	0.169±0.012
Cortex cerebri	Cognitive function	0.174±0.005
Genu corporis callosi	Tract	0.276±0.019
Nucleus rubber	Extrapyramidal system	0.261±0.032

The samples were dried in pre-cleaned quartz vessels at 105 °C to constant mass, which took 36 h. According to our investigations, the water content of specific brain parts differs so considerably, that it was necessary to determine the mass ratio of deep-frozen and dried samples. The dried to wet matter ratios (D/W) was determined for each sample (Table 1). All quoted concentrations in this work refer to dry sample mass.

Samples of biological reference materials (RMs) were analyzed "as received" and their dry masses were determined on non-analyzed aliquots according to procedures prescribed in their certificates. For ENAA and RNAA aliquots of the RMs and brain samples weighing 20 to 100 mg (in some cases 150 mg) were pelletized into 16-mm disks, which were heat sealed in acid cleaned polyethylene (PE) disk-shaped capsules (20 mm in diameter).

Iodine standards for relative standardization in ENAA and RNAA were prepared by pipetting 25 μl aliquots of a solution containing 21.58 μg of iodine per ml that was obtained by dissolution of KI (reagent grade) in dilute NH_4OH (1:5). For ENAA, the aliquots were deposited on a 16-mm diameter disk of chromatographic paper Whatman No. 1, air dried and heat sealed in the PE capsules as for the samples. For RNAA, the aliquots were heat sealed into small PE tubes.

2.2. Irradiation

Irradiation was carried out in the nuclear reactor LVR-15 of the Nuclear Research Institute Řež, plc. at thermal and epithermal neutron fluence rates of $9 \cdot 10^{13}$ and $4 \cdot 10^{12}$ n cm^{-12} s^{-1}, respectively, using a pneumatic transfer facility with a transport time of 3.5 s. The samples and the standards were irradiated individually. For ENAA, the samples and the standards were placed in a Cd cylindrical box of a diameter 34 mm, height 7 mm, wall thickness 1 mm. Cd act as a thermal neutron absorber. Irradiation times were 40 and 120 s for ENAA and RNAA, respectively. A shorter irradiation for ENAA than for RNAA was employed to prevent handling of excessive radioactivity of the Cd boxes.

2.3. Radiochemical separation of ^{128}I radionuclide

Iodine has been determined in human brain samples by oxidising the activated samples in alkaline medium and separating ^{128}I using oxidation–reduction and extraction cycles. Details of analysis have been provided elsewhere [4].Briefly, the sample pellet was removed from its irradiation PE capsule and placed at the bottom of a glassy carbon crucible (Hochtemperature Workstoffe, Germany) in which 300 mg of NaOH was previously melted. Then 25 and 50 μl portions of a 2 mol l^{-1} NaI solution (inactive carrier) and ^{131}I radiotracer (approximately 1 kBq) were pipetted onto the pellet, which was subsequently covered by 3 g of Na_2O_2 and heated at 900 °C for 2 min. After cooling down to about 100–150 °C, the fusion cake was dissolved in approximately 30 ml of hot water under stirring and 1 ml of a 20 w/v % $Na_2SO_3 \cdot 7H_2O$ solution was added and the solution cooled down to 5–10 °C. The iodine in samples (independent of the original bound) was reduced to iodide by Na_2SO_3. Dilute (1:1) nitric acid was carefully added under continuous mixing and cooling (no brown vapours of elementary iodine should appear) until acidic medium (0.1–1 mol l^{-1} HNO_3) was reached. The solution was transferred to a separatory funnel, 10 ml of chloroform and 5 ml of 1 mol l^{-1} $NaNO_2$ solution were added. The oxidation of iodide was ensured with the addition of $NaNO_2$. The liberated elementary iodine was extracted with two chloroform portions (10+5 ml) for 15–20 s. The combined organic fractions were scrubbed with 5 ml of a 0.1 mol l^{-1} $NaNO_2$ solution slightly acidified of 2–3 drops of dilute (1:1) HNO_3, and the extracted iodine was stripped into 7 ml of the 20% Na_2SO_3 solution for counting. The separation procedure took 15–20 min. The chemical yield of separation was between 75–85% (the main losses were due to sputtering on alkaline–oxidative fusion) and was determined in each analysis using ^{131}I radiotracer.

2.4. Counting

The samples and the standards were counted using a coaxial HPGe detector having relative efficiency 23%, FWHM resolution 1.8 keV and the peak-to-Compton ratio of 51 for the 1332.4 keV photons of ^{60}Co. Counting times are given together with the nuclear reactions and parameters of iodine radioisotopes in Table 2. In ENAA, counting was done at a 1-cm distance from the cap of the detector, while in RNAA the 7-ml separated fractions were counted in a 30-ml PE flask positioned directly on the detector cap. Iodine concentrations of brain samples were calculated using the relative method. Every day a standard was measured for calculations, the average values of standards were used.

3. Results and discussion

3.1. Detection limits and uncertainties of ENAA and RNAA

Neutron activation analysis, in general, has a high sensitivity for iodine: the detection limit is about 300 ng g^{-1} (3 σ criterion) in similar condition as described above [4]. The detection limit depends on the concentration of the elements such as Cl, Br and Mn which induce high activities in the samples during neutron

Table 2
Nuclear reactions and parameters of iodine radioisotopes

Radio-nuclide	Nuclear reaction	I_o/σ_o	Half-life	Main γ-energy (absolute intensity)	Determination regime
^{128}I	^{127}I (n,γ) ^{128}I	24.8	24.99 m	442.9 keV (16.9)	ENAA: t_i=40 s, t_d=20 min, t_c=20 min RNAA: t_i=120 s, t_d = 15 – 20 min, t_c=20 min
^{131}I	Radiotracer		8.04 d	364.5 keV (81.2) 637.0 keV (7.3)	t_c as for RNAA

activation. Thermal neutrons are eliminated to a large extent by irradiating the samples under a Cd box. The elimination of thermal neutrons reduces the presence of other induced activities by about two orders of magnitudes and facilitates the determination of the ^{128}I. The interferences can be reduced but not completely eliminated by ENAA, in which case the detection limit is significantly improved to 10–40 ng g^{-1}.

Much more significant reduction of the background can be only obtained by radiochemical separation of the interfering radionuclides. In this case, the background below the 442.9 keV full energy peak of ^{128}I is influenced only by the Compton scattering of the photons of 637.0 keV of the ^{131}I radiotracer (Table 2). Therefore, the radiotracer should be used only in such quantities to compromise between achieving reasonable good counting statistics for the full energy peak of 364.5 keV and not very high background from the photons of 637.0 keV in the lower energy region. In the specified experimental conditions, a detection limit of 1 ng g^{-1} was obtained using RNAA [4].

From the above described reasons, significantly lower uncertainty is obtained by RNAA compared to ENAA at very low iodine levels. Table 3 shows several examples of results achieved by ENAA and RNAA for identical human brain samples that were analyzed by both modes. Therefore, whenever the determination of iodine at low levels with a low uncertainty is required, RNAA should preferably used. In this table, results obtained in Řež and in Berlin for identical or similar samples are also included.

Table 3
Comparison of ENAA and RNAA for low-level determination of iodine in human brain samples (ng g^{-1} dry mass±uncertainty*)

Brain region	ENAA (Řež)	RNAA (Řež)	Mean±SD (ENAA+RNAA)	RNAA Berlin (left side)	Mean± SD (three modes)
(G) Cortex frontalis parasagittalis (right side)	841±112	750±29	795±64	730±40	773±59
(G) Cortex cerebri (right side)	231±36	307±11	269±54	347±37	295±59
(M) Gyrus hippocampus (right side)	651±69	600±22	625±36	653±24	635±30
(W) Genu corpori callosi (right side)	505±68	639±23	572±95	630±14	591±75
(M) Globus pallidus (left side)	671±83	635±24	653±25	640±20	649±19
(M) Nucleus rubber (left side)	635±55	–		590±30	612±10

*Combined uncertainty in which all standard uncertainties except for counting statistics are equal to ~3% and ~4% for ENAA and RNAA, respectively.
G, M or W indicate that the region has been classified as grey matter, as mixed composition or as white matter, respectively.

Table 4
Results of iodine content in NIST reference materials by ENAA and RNAA (ng g^{-1} dry mass±uncertainty*)

Reference material	Certified[a], consensus[b] or literature values	Our individual results by ENAA	Our results by ENAA, mean±SD	Our results by RNAA, mean±SD	Our results by ENAA and RNAA, mean±SD
SRM Bovine Liver 1577a	243[b]	282±24 258±18 267±21	269±12	303±10	286±24
SRM Bovine Liver 1577	234±31[b] 222±15[26] 209±21[26] 270±36[26] 180±12[26] 187±12[26]	267±27 236±20 282±28 265±27	263±19	238±9	250±17
SRM typical Diet 1548a	759±103[a] 600±200[3]	667±44 666±46 590±40	641±44		
SRM bone meal 1486	110±40[3]	69±16 73±23 98±12	80±16	79±3	79±1

*Combined uncertainty.

3.2. Quality control analysis

Accuracy of our results can be evaluated using NIST Bovine Liver 1577 and 1577a RMs. The elemental composition of these RMs and the human brain is similar. NIST Bone Meal 1548a and Typical Diet 1486 RMs were also selected for quality control purposes to cover concentration ranges lower and higher than Bovine Liver. The data of our measurements by both ENAA and RNAA can be seen in Table 4. Table 4 shows that the results obtained are in good agreement with the uncertainty margins with NIST certified (whenever available: Typical Diet 1486), consensus or literature values, thus proving the accuracy of our data [28]. Another quality control exercise was performed by analyzing the human brain samples by ENAA and RNAA, respectively. A good agreement within the uncertainty margins was observed (Table 3). A third quality control measure consists of comparing RNAA results obtained in Řež and in Berlin for identical samples. The two RNAA procedures show an good agreement (Table 3).

3.3. Results for human brain

The role of trace elements has been subject of a conjecture, and reports of different authors are often conflicting and contradictory. A major reason for these discrepancies is the difficulty in analysing trace elements at low levels and the problems existing in collection of specimens without contamination. Therefore from the beginning we made considerable efforts to optimize all stages of the analytical procedure to avoid the contamination. Moreover, there is a going consensus that some of the controversy may be due to systematic errors. Thus a

Table 5
Comparison of iodine concentrations of two hemispheres of the same individuals determined by ENAA in Řež and RNAA in Berlin (ng g^{-1} dry mass)

Brain region		Right side	Left side	Mean±SD (right and left side)
(M) Pulvinar thalami		1150, 475	2271, 898	
		477, 1174	865	
	Mean±SD	819±396	881±23	850±309
(M) Putamen		655, 641	780, 715	
		900	865	
	Mean±SD	732±145	787±75	759±168
(G) Vermis cerebelli		361, 580, 562	423, 692, 395	
	Mean±SD	501±122	503±164	502±129
(M) Nucleus caudatus	Mean±SD	447±32	600±28	523±108

G or M indicate that the region has been classified as grey matter or as region of mixed composition, respectively.

major trend should be to practice quality control by the regular use of RMs, which we frequently did together with other quality control measures.

By using factors calculated from the water content of the samples it is possible to compare the results obtained by different analytical techniques and to convert values from the literature expressed on a wet matter basis (Table 1).

Tables 3,5,6 and 7 give the obtained results. When not indicated otherwise, RNAA results refer to measurements in Řež. From the good agreement of the data in Table 3, it can be concluded that the determination of iodine by nondestructive method, ENAA and the destructive procedure, RNAA, based on alkaline–oxidative fusion followed by extraction of elemental iodine in chloroform, methods described here, represent useful and sensitive NAA techniques for the determination of iodine in human brain samples. Analysis of several NIST RMs by both ENAA and RNAA, showed a good agreement with the certified, consensus or literature values proving the accuracy of the applied NAA modes (Table 4). The precision of the analytical techniques was tested by repeated analysis of RMs. The precision, in terms of relative standard deviation is about 4% for RNAA and about 13% for ENAA, respectively. The RNAA technique has advantages: RMs can be verified directly, irradiated sample decomposed with using radiotracer ensured excellent radiochemical purity and high precision (low uncertainty). The disadvantages of the method: relatively slow and requires most manipulation (hence greatest radiation hazard) and samples need to be dried before analysis. From the results presented in Table 3 it is evident that the values obtained in present work are close to those obtained by other radiochemical method applied in Berlin. It can also be seen from the data that no significant differences were found between the three NAA modes.

Table 6
Iodine levels in various control human brain regions determined by ENAA (ng g^{-1} dry mass±uncertainty)

Brain region	Iodine concentration mean±SD	Mean±SD (right and left side)
(M) Pulvinar thalami	1150±36, 2271±80, 898±77, 475±40, 549±30, 1174±57, 995±57	874±299
(M) Thalamus	1732±76, 1055±84, 2090±61, 458±26, 656±45	723±304
(G) Gyrus hippocampus	651±69, 1853±124, 2485±75, 652±46, 793±35, 1079±54	794±202
(G) Vermis cerebelli	361±26, 423±36, 692±67, 1768±53, 553±32, 782±34	562±139
(W) Genu corpori callosi	245±21, 295±25, 425±25, 419±25	346±90

G, M or W indicate the region has been classified as grey matter, as a region of mixed composition or as white matter, respectively.

Table 7
Comparison of iodine content of Hungarian and German control human brain regions (ng g^{-1} dry mass, mean±SD)

Brain region	Hungarian	German
	ENAA+RNAA, Řež; $n=3$	RNAA, Berlin; $n=5$
(G) Cortex frontalis parasagittalis	773±59	104±33
(M) Nucleus caudatus	523±108	86
(M) Putamen	759±168	159±137
(G) Cortex cerebri	295±15	176*, 204*
(G) Gyrus hippocampus	635±30	184*, 197*

*Literature values: [32].
G or M indicate that the region has been classified as grey matter or as region of mixed composition, respectively.

The data for iodine are not complete enough to draw far-reaching conclusions. Nevertheless the results suggest some tendencies. From the data in Tables 5,6 and 7 it should be appreciated that there is a considerable scatter in iodine concentrations between the individuals and between the regions. Consequently, an average value in different brain regions can only be established with difficulties. Very high iodine quantities (~2 μg g^{-1}) were found in brain regions of three control subjects and therefore these patients were excluded from mean calculations. The reason may be a special medical treatment or/and drug therapies. The increasing tendency with treatment for iodine suggest that fixation of iodine in human brain regions is almost irreversible. Whether this is due to differences in the permeability of regions in the retention by the brain or to some other mechanism is an open question, but clearly organ related effects must be taken into account.

From our data in Table 5 it can be seen that corresponding regions from the two hemispheres revealed similar concentrations in general which is in agreement with other essential elements' studies [29]. As it seems from the standard deviation, there is a wide range for individual values, especially in some brain regions (e.g. pulvinar thalami, thalamus) (Tables 5 and 6). This study indicates that beside differences in iodine intake with foods, the main factor of the high inter-individual variability of this element concentration in human brain regions may be a marked difference in individual accumulation or elimination capabilities.

Although iodine has received more attention than the other elements, no or little information is available on its topographical distribution in human brain [2]. The values in Tables 3,5,6

and 7 show that iodine is heterogeneously distributed within the control human brain similarly to other essential elements and in accordance with our previous results [29]. The resemblance of iodine distribution in both hemispheres indicate that the differences for various human brain regions are not at all accidental. The heterogeneous distribution of elements in human brain may partly be due to the various cell densities, cell volumes and different cell type within different regions. The lowest iodine concentration can be seen in white matter (genu corpori callosi) (Table 6). This can be explained by its very low cell density. Surprisingly, low iodine concentration can be found in some cortical structure which are in connection with cognitive function (e.g. cortex cerebri). High iodine concentrations were found in brain regions involved in sensory system (pulvinar thalami) and in limbic system (gyrus hippocampus). The grey and white matter of gyrus hippocampus was found to be decreased in post-traumatic stress and in major depression [30,31]. Another interesting finding is that some regions which can be classified on the basis of their physiological function contained similar high levels (e.g. basal ganglia) suggesting that there is some relation between the iodine profile of the brain and its function.

One of the aims of our present work was to compare the Hungarian and German control data in order to examine whether differences in iodine content of human brain regions are typical in the two populations. Iodine concentrations found in the present study for Hungarian control brain regions (mean age: 75 years) and obtained in our previous work for German control brain regions (mean age: 58 years) are given in Table 7 [25]. Our results illustrate that iodine content is consistently lower in German control specimens than in Hungarian control human brain regions.

According to our results the iodine content of the brain depends on the geographical area, the local pasturage, the mode and kinds of food consumption, whether or not supplements (e.g. iodinated salt) have been used. In the literature values are reported about 200 ng g^{-1} (dry mass) determined by pre-chemical separation NAA for cerebral cortex and hippocampus of English and Canadian control subjects, mean age: 63 and 60 years, respectively (Table 7). The concentration for iodine turned out to be similar for cerebral cortex and hippocampus taking into account that hippocampus consists of grey and white matter. Further investigations are needed to find out the role and the origin of the lower concentration in brain areas of German patients.

We have compared the mean values of the two groups and the individual values of Hungarian and German patients of the same age using the same method and no evidence of iodine concentration changes with age was noted. The essential trace elements that remained within narrow concentration limits throughout adult life suggest the presence of an efficient homeostatic mechanism of their regulation in the brain. It is possible that an essential trace element shows a nonessential type of distribution if for some reasons the external effect remains stronger than that of internal control. In contrast to the essential trace elements it shows no similarity between the two hemispheres, its concentrations exhibit great variation in all samples. This phenomenon was seen in subjects with extreme high iodine values (e.g. left side of pulvinar thalami, Table 5).

It is known that thyroid necessitates some essential elements (e.g. Zn and Se) other than iodine in the thyroid hormones, i.e. thyroxine (T_4) and 3,5,3′ triiodo-thyronine (T_3). It is assumed that a balance in trace elements is present in the brain, and perhaps an increase of iodine levels over times take place at the expense of other essential elements. At present the effects of accumulation or imbalance of trace elements in brain are not known. We have studied the possible elemental correlation using our previous and new data on elemental distribution in control subjects [26]. For that purpose correlation was checked for every possible combination of the three elements (I, Zn and Se), using the separate data for each individual and brain region. The within-group correlation data showed no significant correlation.

As shown both by the literature and our investigations, trace element concentration in tissues shows a considerable variations of different part of the world [29]. If these discrepancies are not caused by lack of analytical performance, as we believe is in our case, to generate control (normal) values in brain, only data from a given country should be taken into account. In studies concerned with individuals or populations for example decision on the need for a salt iodination programme, it is clear that the data about concentration levels of iodine in different foodstuffs must be also accurate and reliable [24].

4. Conclusion

In the Nuclear Research Institute, Řež, several accurate and reliable techniques have been developed for the determination of ^{127}I in different biological and diet samples using a short irradiation to induce ^{128}I. From our results it can be concluded that both ENAA and RNAA methods, applied in this work, represent useful and sensitive techniques for the determination of iodine in human brain samples at the ng g^{-1} level. In our present study further data on iodine levels in human brain tissue are given, which are largely missing in the literature. Our work show regional differences of the brain iodine content. From our data it can be seen that iodine levels of Hungarian control brain regions are significantly higher than those in German control ones. The reason for these discrepancies is not clear at present, the probable explanation may be of geographical nature. Hopefully, this survey of the existing discrepancies will be a challenging stimulus for further research work.

Acknowledgements

This research project has been supported by the European Commission under the 6th Framework Programme through the Key-Action: Strengthening the European Research Area, Research Infrastructures, Contract No. RII3-CT-2003-505925 and the Grant Agency of Hungary, OTKA (Grant No. 063228). The authors also thank for provision of human brain samples to Dr. A. Réffy, Hospital Balassa and Institute of Traumatology, Budapest, Hungary.

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