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The value of intraoperative ultrasound (IUS) examination for the visualization of metastatic cerebral lesions, compared with computed tomography (CT) and magnetic resonance(MRI)

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Study aim. The purpose of this study is: 1. to assess the value of intraoperative ultrasonographic examination (IUSG) in confirming intraoperatively the presence of metastatic tumours detected preoperatively by computed tomography (CT) and magnetic resonance tomography (MRI), 2. to evaluate an accordance of the numbers, localization and dimensions of metastatic tumours recognized preoperatively (CT and MRI) with those shown by intraoperative USG, 3. to comparatively assess the images of metastatic tumours found in preoperative CT and MRI examinations and in intraoperative USG examinations.
Material and methods. Sixteen patients were operated upon for metastatic intracranial tumours from various primary foci. All patients had diagnostic brain examinations before the operation: MRI and CT in 7 cases, only MRI in 3 cases, only CT in 6 cases. Intraoperative USG examination was done in all cases. Retrospective analysis included: 1. comparative assessment of the images of metastatic tumours in intraoperative USG versus preoperative MRI and CT findings, 2. analysis of the number, localization and dimensions of metastatic tumours detected preoperatively and in intraoperative USG examination.
Results. The comparison of the greatest dimensions of metastatic lesions measured in CT and MRI findings, and in intraoperative USG based on Student t test showed no statistically significant differences between the examinations performed, $p=0.2449$. No statistically significant difference were found either between the numbers of metastatic lesions detected by these methods, $p=0.71830$. In the analysis of the images of metastatic lesions in preoperative examinations, the non – homogenous foci with margin enhancement after administration of gadolinium or contrast medium, with inner area not enhanced (necrosis?) were found in 8 cases (10 foci lesions), and in USG in 6 cases (9 focal lesions). In one case (one lesion) USG showed that the tumour was hypoechogenic as a whole, without areola around it.
Conclusions. Intraoperative USG examination is a precise method of detection and localization of previously recognized metastatic brain tumours.Intraoperative USG is comparable with CT and MRI findings in the assessment of dimensions of metastatic lesions. Intraoperative USG is a useful method in the selection of the biopsy site and in the introduction of leaders for brahytherapy during an operation.

Przydatność śródoperacyjnego badania USG w wizualizacji zmian przerzutowych mózgu w porównaniu z przedoperacyjnym badaniem KT i MR

Cel. Celem pracy jest: 1. ocena śródoperacyjnego badania ultrasonograficznego (ŚUSG) jako metody potwierdzającej (śródoperacyjnie) obecność ognisk przerzutowych, wykrytych badaniami przedoperacyjnymi: tomografią komputerową (KT) i tomografią rezonansu magnetycznego (MR); 2. ocena zgodności liczby, umiejscowienia i wymiarów ognisk przerzutowych w mózgu w badaniach przedoperacyjnych KT i MR ze śródoperacyjnym USG; 3. porównawcza ocena obrazów zmian przerzutowych w przedoperacyjnych badaniach KT i MR oraz ŚUSG.
Materiał i metody. Materiał stanowiło 16 przypadków chorych, operowanych z powodu przerzutów do mózgu, z pierwotnym rozpoznaniem nowotworu złośliwego w różnych umiejscowieniach. Wszyscy chorzy mieli wykonane badania diagnostyczne mózgu przed operacją zmian przerzutowych: w 7 przypadkach były to badania MR i KT, w 3 przypadkach tylko MR, w 6 przypadkach tylko KT. U wszystkich chorych było wykonane śródoperacyjnie badanie USG.

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Retrospektywnie dokonano: 1. porównawczej oceny obrazu zmian przerzutowych w śródoperacyjnie wykonanych badaniach USG z oceną przedoperacyjną na podstawie MR i KT; 2. analizy liczby, umiejscowienia i wymiarów zmian przerzutowych, wykrytych badaniami przedoperacyjnymi i ultrasonografią śródoperacyjną.
Wyniki. Porównawcza analiza statystyczna (testem t-Studenta) największych wymiarów ognisk przerzutowych, mierzonych w badaniach KT i/lub MR oraz ŚUSG nie wykazała znamiennej stystycznie różnicy pomiędzy tymi badaniami, p=0,2449.
Nie stwierdzono również znamiennej stystycznie różnicy odnośnie liczby ognisk przerzutowych, p=0,71830.
W analizie obrazów zmian przerzutowych w badaniach przedoperacyjnych, niejednorodne ognisko z brzeżnym wzmocnieniem, po podaniu gadolinium Gd-DTPA lub środka cieniującego, wewnątrz z obszarem nie ulegającym wzmocnieniu (martwicą?), stwierdzono w 8 przypadkach (10 zmian ogniskowych), w badaniu USG w 6 przypadkach (9 zmian ogniskowych). W jednym przypadku (1 ognisko) zmiana w badaniu USG była w całości hypoechogeniczna, bez otoczki.
Wnioski. 1. ŚUSG jest precyzyjną metodą, pomocną w śródoperacynym wykrywaniu i lokalizacji wcześniej rozpoznanych zmian przerzutowych w mózgu; 2. ŚUSG jest metodą porównywalną z KT lub MR w ocenie wymiarów ognisk przerzutowych; 3. ŚUSG jest metodą przydatną przy wyborze miejsca pobrania biopsji ze zmiany ogniskowej lub wprowadzenia prowadnicy do brachyterapii, podczas operacji.

Key words: intraoperative ultrasound, computed tomography, magnetic resonance imaging
Słowa kluczowe: śródoperacyjna ultrasonografia, tomografia komputerowa, rezonans magnetyczny, przerzuty do mózgu

Intraoperative ultrasonographic examination (IUS) could play an important role in the visualization of pathological changes, their extent and relation to the surrounding anatomic structures [1-3]. The use of IUS during neurosurgical operations reduces the duration of the procedure and the area of damage to brain tissue and decreases the incidence of postoperative complications [4, 5]. The aims of our study were following:

1. Assessment of intraoperative US as a method for intraoperative confirmation of metastatic lesions demonstrated before the operation by computerised tomography (CT) and magnetic resonance tomography (MRI).
2. Evaluation of the accordance between the numbers, localization and size of metastatic lesions in the brain, detected preoperatively by CT and MRI and intraoperatively by US.
3. Comparative evaluation of images of metastatic lesions in preoperatove CT and MRI versus intraoperative US.

Material and method

The study was done in a group of 16 patients, 8 women and 8 men, operated upon for cerebral metastases from malignancies in various sites. Their age ranged from 22 to 64 years.

Lung cancer was the primary tumour in 7 cases (microcellular cancer in 2 cases), breast cancer in 4, colonic cancer in 2, testicular cancer in 2 and gastric cancer in 1case. All patients had diagnostic procedures before the operation: MRI and CT in 7 cases, only MRI in 3 cases, only CT in 6 cases. Intraoperative US was carried out in all cases.

CT was done using a spiral unit by standard method: layer thickness in the area of the posterior cranial fossa was 5 mm, and 8 mm in the remaining studied area. MRI was performed with 0.5 or 2 tesla units in sequences SE T1, PD and FSE T2 weighted in transverse, frontal and sagittal projections. CT was carried out without contrast medium in one patient in poor general condition and threatening invagination, in the remaining cases the examination was done in two steps, before and after intravenous contrast medium administration (in CT) and SE T1 before and after gadolinium Gd-DTPA administration (in MRI).

A 6.5 MHz sector probe was used for intraoperative US, probe 5 MHz was applied in several additionall cases. In the first stage, the study was carried out across the dura in the area exposed for operation. The second examination, especially in cases of multiple lesions situated more deeply or/in not exceeding 10 mm in diameter, was carried out from brain surface. Epidermal lipid markers were used in cases of lesions below 2 cm. They facilitated significantly the determination of the site and extent of craniotomy.

Metastases of up to 5 mm in size, lying at cortical or cortical-subcortical depth (to 15 mm), were removed during one-stage procedure under continuous IUS observation. Punch forceps with 5 mm window were used after cortex incision and coagulation. Larger tumours and those situated deeply in white matter were removed by microsurgical method making a „key hole" tunnel (Yasargil). The operation led to complete or partial excision of metastatic lesions in 15 patients, tumour biopsy was done in one case. In all cases the diagnosis of metastases was confirmed by microscopic examination.

In cases of one-stage treatment of multiple metastatic lesions each lesion was sent separately for histological examination. The microscopic pattern of removed tumours corresponded with the primary diagnosis. Multiple lesions in all cases had identical histological pattern.

The following measurements were performed:

1. intraoperative assessment of the pattern of metastatic lesions in intraoperative US and preoperative MRI and CT examinations;
2. analysis of the number, localization and size of metastatic lesions found in preoperative diagnostic procedures and intraoperative US.

In preoperative MRI examinations the size of focal lesions was measured in SE T1 weighted sequences after gadolinium Gd-DTPA administration, and in CT after contrast medium injection.

Results

The results of the comparison of the number, localization and size of metastatic lesions found in MR an/or CT, and in intraoperative US are presented in Table I. Statistical analysis (Student t test) comparing the greatest dimensions of metastatic foci measured in CT and/or MRI and intraoperative US failed to show statistically significant differences between these results (p= 0.2449).

Preoperative examinations showed 22 focal lesions in the brain in 16 studied patients. In 11 cases (18 metasta-

Tab. I. Comparison of the number of lesions, their localization and dimensions of metastases in preoperative MRI and/or CT and in intraoperative US examinations

No	localization		dimensions		(mm)	
	USG	MRI/CT	IUS	MRI/CT	IUS	MRI/CT
1.	right frontal lobe thalamus right side	right frontal lobe thalamus right side left frontal lobe	2	3	26x25 36x31	25x23 34x29 4x4
2.	left temporal lobe cerebellum	left temporal lobe right frontal lobe	2	2	15x12 18x11	13x11 5x4
3.	right occipital lobe	right occipital lobe	1	1	42x29	37x27
4.	left parietal lobe left temporal lobe left temporal lobe	left parietal lobe	3	1	30x30 8x6 8x5	25x25
5.	right frontal lobe	right frontal lobe right frontal lobe	1	2	22x18	19x18 11x10
6.	frontal area	frontal area	1	1	41x37	45x41
7.	r. cerebellar hemisphere	r. cerebellar hemisphere	1	1	31x25	28x26
8.	left parietal lobe	left parietal lobe left parietal lobe	1	2	14x10	13x11 15x9
9.	left temporal lobe	left temporal lobe	1	1	52x28	38x32
10.	l. cerebellar hemisphere	l. cerebellar hemisphere	1	1	25x23	30x25
11.	l. temporo-occipital area l. temporo-occipital area	l. temporo-occipital area	2	1	20x19 8x7	23x19
12.	l. cerebellar hemisphere	l. cerebellar hemisphere	1	1	25x23	35x30
13.	l. temporo-occipital area	l. temporo-occipital area	1	1	37x30	40x35
14.	right parietal lobe	right parietal lobe	1	1	11x10	10x9
15.	right occipital lobe	right occipital lobe	1	1	50x35	40x22
16.	l. cerebellar peduncle pontocerebellar angle	l. cerebellar peduncle pontocerebellar angle	2	2	15x10 30x25	13x11 26x19

tic lesions) an agreement was noted with regard to the number of lesions in CT and/or MRI versus intraoperative US. In there cases MRI and/or CT found more lesion than intraoperative US. In one case focal lesion found in MRI was in the contralateral cerebral hemisphere to craniotomy and could not be visualised. In two cases intraoperative US showed more focal lesions than earlier CT and MR. In one of these cases preoperative CT was done in one stage, without contrast medium administration, which decreased the diagnostic value of this examination.

No statistically significant difference was noted in the number of metastatic foci demonstrated in MRI and/or CT and intraoperative US ($p = 0.7183$). Student's test was used for the comparison.

In the analysis of the images of metastatic lesions in preoperative CT and /or MRI and IUS homogeneous structure of cerebral metastases in MR and CT with significant homogenous enhancement after gadolinium Gd--DTPA or contrast medium administration was observed in three cases, and this was seen in six focal lesions. Homogeneous metastasis with medium intensity enhancement was found in MR/CT in two cases (three focal lesions). Generally, findings of a homogeneous focus in CT and/or MRI were obtained in five cases, and nine metastatic lesions.

A homogeneous hyperechogenic foci were found by intraoperative US in nine cases (12 metastatic lesions).

Non-homogenous lesions – in first stage of the procedure with evident, again non-homogeneous, enhancement in the second stage was visualized in MRI/CT in three cases (three foci).

Non-homogeneous lesion with marginal enhancement after gadolinium Gd-DTPA administration or after contrast medium, with central area not showing enhancement (necrosis) was found in eight cases (10 focal lesions). The image of cystic lesion with hyperechogenic area was seen in US in six cases (nine focal lesions).

In one case (one focal lesion) the change in US was hypoechogenic as a whole, without envelope.

MR/CT demonstrated evidence of bleeding into focal lesions in six patients with primary diagnosis of breast cancer, gastric cancer, testicular cancer, rectal cancer and two cases of lung cancer. Bleeding was manifested by enhancement signal in SE T1 weighted sequences in MRI, while in CT the index of radiation weakening was noted to be increased (hyperdence lesions). These changes showed moderately intense and usually non-homogeneous enhancement in these cases in the second stage of the examination after contrast administration.

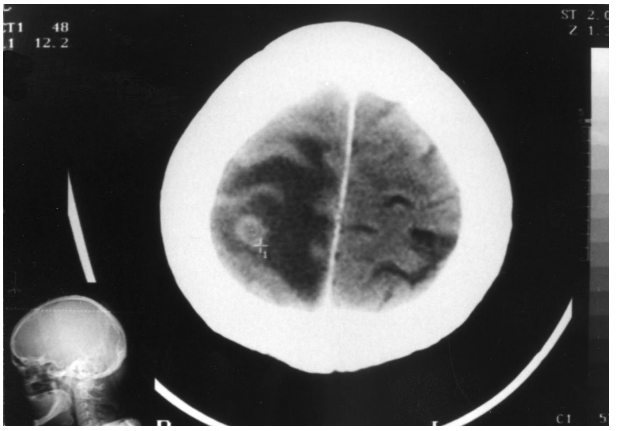

Fig.1. Homogeneous well outlined focal lesion 12x11mm in size, in the right parietal lobe greatly enhanced by contrast injection (in CT and MRI). In intraoperative USG the tumour was hyperechogenic (Fig. 1e). Extensive oedema around the lesion – visible in Fig. 1a,b,c as hypodense area (in CT) and hypointese area in SE T1 images, and hyperintense in FSE T2 images (Fig. 1d).
a) CT after contrast injection, axial projection
b) MRI, SE T1 image after gadolinium administration, axial projection
c) MRI, SE T1 image after gadolinium injection, frontal projection
d) MRI, FSE T2 image, axial projection
e) intraoperative USG, axial projection

In two of these cases strongly hyperechogenic changes were found In intraoperative US, possibly as result of bleeding.

Oedema around metastatic lesions was observed in 22 metastatic foci in preoperative CT and/or MRI. Usually an extensive area of oedema was present, exceeding 30 mm, only two focal lesions were surrounded by less extensive oedema; in one of these cases the diameter of the metastatic lesions was 4 mm, in the other case it was 35x30 mm (with evidence of bleeding in its centre).

In 10 cases (13 focal lesions) an agreement was observed between CT and MR and IUS examination with regard to the area of oedema around the focal lesions in the brain. On the other hand, in 6 cases (9 metastases) IUS failed to demonstrate oedema visible in CT and/or MR, with the area of oedema in CT and MR exceeding 30 mm in diameter. In 11 cases MR and/or CT demonstrated mass effect, with compression and shifting of ventricles. Such changes have not been described in the IUS examinations, which could have been due to routine dehydration of patients before neurosurgical operations.

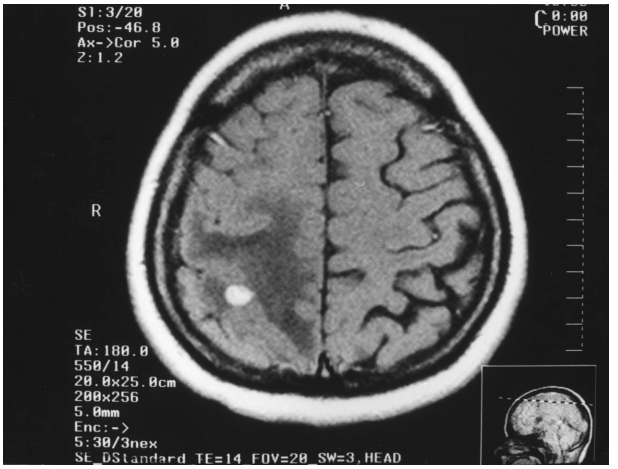

Fig. 1b

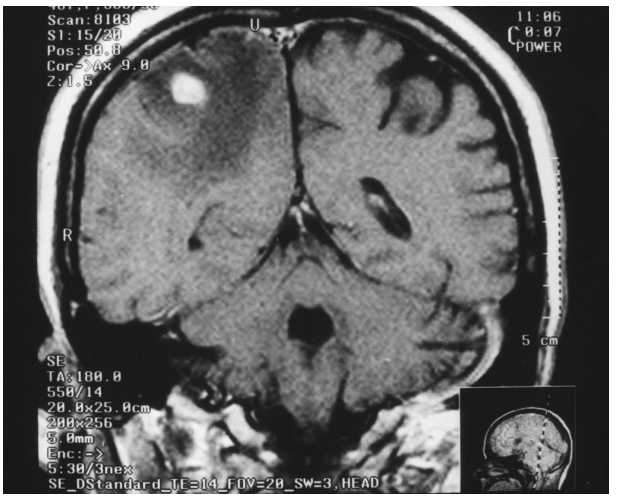

Fig. 1c

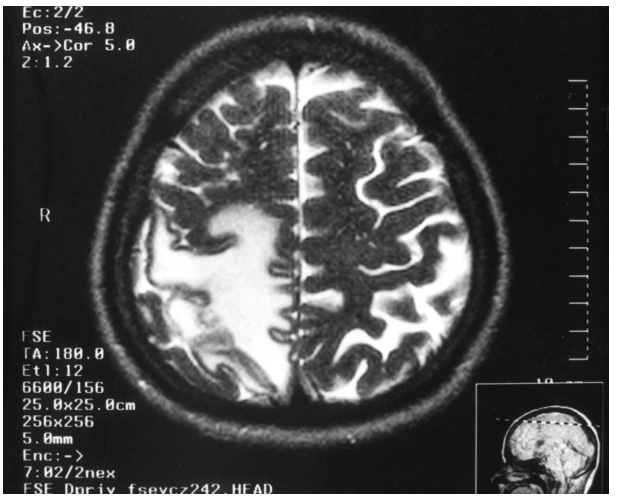

Fig. 1d

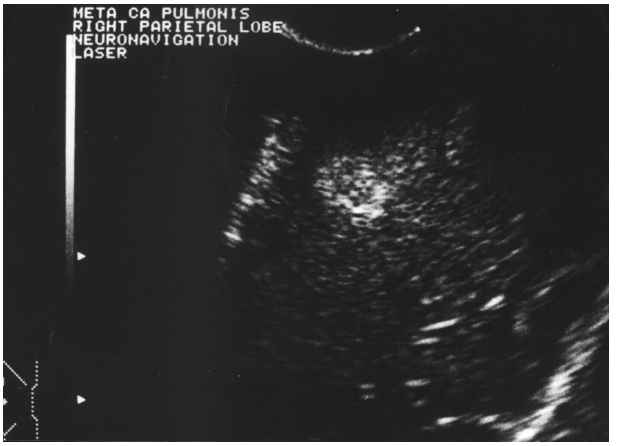

Fig. 1e

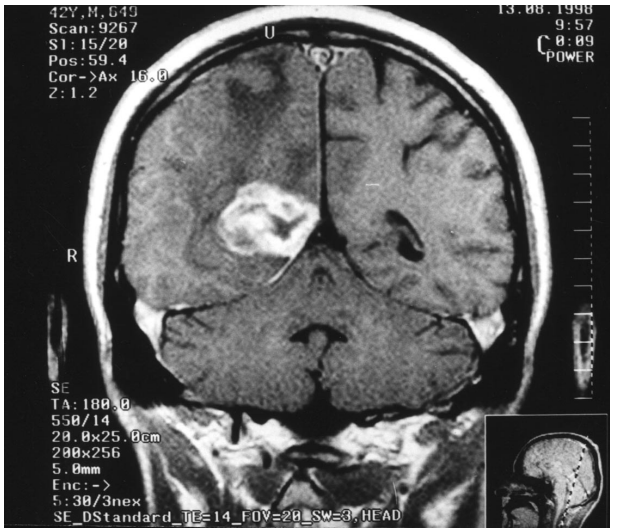

Fig. 2. Non-homogenous tumour in right occipital area, strongly enhanced by gadolinium injection, Fig. 2a. In intraoperative USG (Fig. 2d) hyperechogenic lesion, again non-homogenous. Extensive oedema around the tumour is visible in MRI (Fig. 2c), with mass affect evidenced as compression of posterior horn of right lateral ventricle.
a) MRI SE T1 after gadolinium, frontal projection
b) MRI SE T1 after gadolinium, sagittal projection
c) MRI FSE T2, axial projection
d) intraoperative USG, axial projection

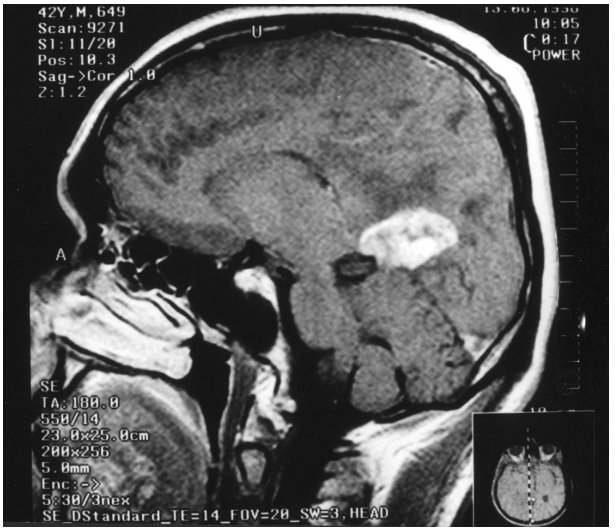

Fig. 2b

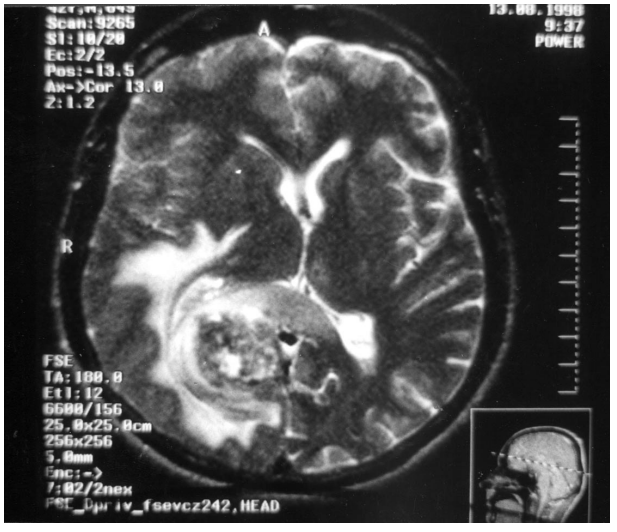

Fig. 2c

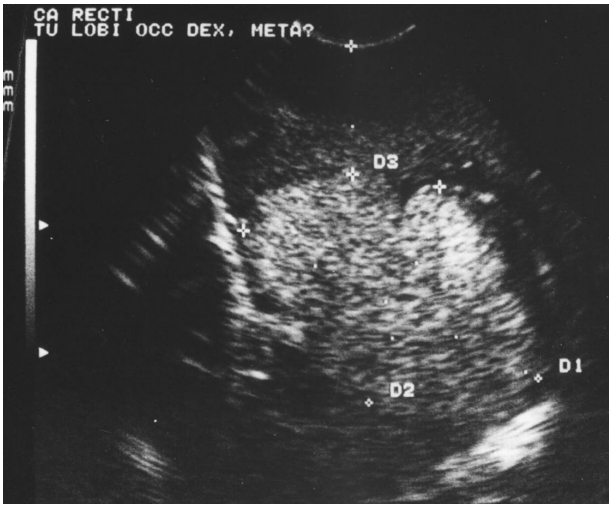

Fig. 2d

Discussion

The comparison of preoperative CT and MR with IUS examinations demonstrated an agreement of results in 11 out of 16 cases with respect to the number of focal lesions in the brain. Differences were found in 5 cases, in three cases CT and/or MR demonstrated a higher number of lesions. Including the localization of one lesion in the area contralateral to the cerebral hemisphere operated upon, false negative IUS result were obtained in two cases. Later on, control MR examination confirmed the presence of these lesion and their metastatic character (size increase over period of observation).

In two cases IUS disclosed more focal lesions than in preoperative examinations. In one of these cases two foci were found not seen earlier in preoperative examinations, but the preoperative diagnostic procedure included only one – phase CT examination because of poor condition of the patient. In the other case preoperative radiotherapy had been applied, and preoperative examinations failed to show a focal lesion in the irradiated area. Thus one false negative result was obtained in CT and/or MR.

In the group of 18 focal lesions demonstrated in preoperative CT and /or MR compared with IUS full agreement was obtained in all cases of the location of metastatic lesions in the brain, this corresponds with literature reports [2]. In the analysis of 18 metastatic lesions demonstrated in both preoperative and intraoperative examinations it was observed that in IUS: 5 focal lesions were larger in two dimensions by 2-3 mm, 5 focal lesions were larger by 3-5 mm, 2 focal lesions were larger by more than 5 mm. In two metastatic lesions a near agreement

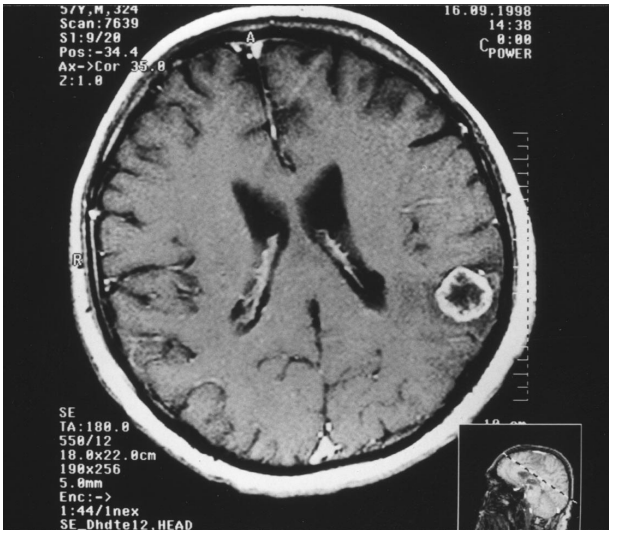

Fig. 3. Cystic focal lesion situated in left parietotemporal area. Intense margin enhancement after gadolinium injection, with hypointense area (necrosis), Fig. 3a. Hyperechogenic border around the tumour with hypoechogenic inner area in intraoperative USG examination. Oedema around the lesion, with compression of the left lateral ventricle in MRI

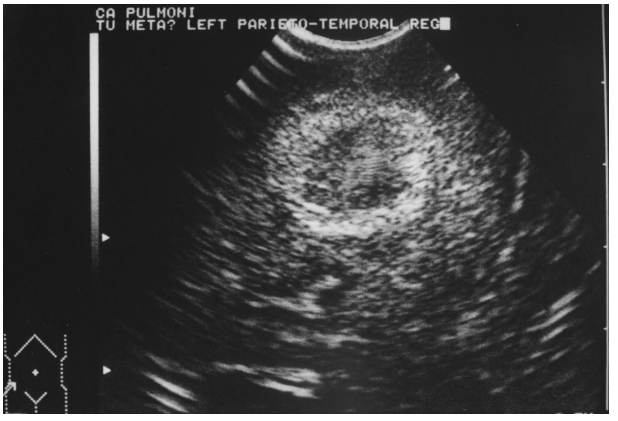

Fig. 3c

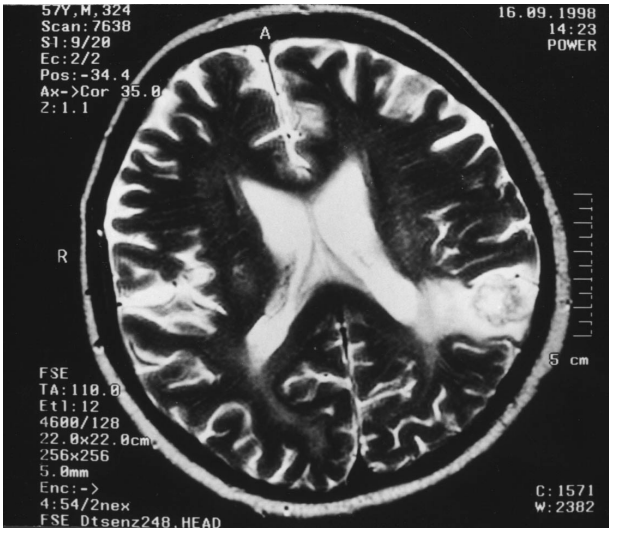

Fig. 3b
a) MRI SE T1 after gadolinium, axial projection
b) MRI FSE T2, axial projection
c) intraoperative USG, axial projection

(differences of 1-2 mm) in one dimension was observed in 2 focal lesions.

On the other hand, 4 lesions were larger in preoperative CT and/or MRI by 2-6 mm. According to literature date [6, 7] the volume of metastatic tumors is greater in IUSG than in MRI.

The analysis of the images of metastatic foci in the performed preoperative and intraoperative examinations showed homogeneous hyperechogenic foci in IUSG in 9 cases, which included 12 metastatic foci, and in CT/MRI they were observed in 5 cases with 9 metastatic foci. Cystic lesions with hyperechogenic halo in IUSG were found in 6 cases with 9 focal lesions and in 1 case this lesion was without halo. In CT/MRI examinations this was observed in 8 cases (10 focal lesions). Agreement was lacking in case of one cystic metastatic lesion. These observations are comparable with literature reports [7, 8].

This may be of practical importance in the selection of the site for biopsy during neurosurgical operation or for leader introduction for brachytherapy under IUSG control. The remaining changes in CT/MRI were homogeneous. No oedema halo was observed around 6 focal lesions.

Conclusions

1. Intraoperative USG examination is a precise method helpful in intraoperative detection and localization of previously recognized metastatic brain lesions:
   a) false negative results were obtained in IUSG and 5% in preoperative CT and/or MRI examinations for the detection of focal lesions,
   b) no statistically significant difference was found in the determination of the number of metastatic foci in MRI and/or CT in comparison with IUSG, $p=0.71830$.
2. IUSG is a method comparable with CT or MRI in the assessment of the size of metastatic foci, a comparison by Student t test failed to demonstrate a statistically significant difference between these methods, $p=0.2449$.
3. IUSG is useful for the choice of biopsy site during the operation. In the assessment of cystic lesion lack of agreement between IUSG results of CT and/or MRI was present in only one lesion that is in 4.5%.

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