New neuroradiological methods for the support of neurosurgical decision making

Ph.D. thesis

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Pécs

2009

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„our World... advanced by imaging...”(1996 lecture title - adopted freely from the Hungarian poet Vörösmarty…)

Preface:

Professing in medical diagnostics in the last 25 years I had the chance to experience a revolution of imaging. Practicing continuously at the same department I also had the opportunity to treat clinical cases of various nervous CNS diseases, further help their adequate therapy. New methods as CT and MRI and their special imaging methods were of great importance in determining appropriate neurosurgicalgery therapies. Most of my activity concentrated around the question: how to support neurosurgeon, neurologist, paediatrist and orthopaedist colleagues in their treatment decisions to select minimally invasive but effective therapy methods.

I consider this paper as a part summary of my professional experience, specially concentrating on introduction of new neuroradiological methods supporting neurosurgical decision makings, further analyzing their results with clinical scientific accuracy.

1. Objectives

Evolution in medical diagnostic imaging in the last decades provided the opportunity to **establish objectives** of my scientific activity as follows:

What imaging methods could optimize the support of neurosurgical interventions? What could be the role of the neuroradiologist in this contribution, to achieve optimal result with minimally invasive methods and observing "nil nocere" principle.

- Objectify cerebral edema cases and evaluation of intervention effectiveness, measuring brain tissue water content by routine MRI method establishing so called "Water Content maps.
- Older aneurysm clips were MRI contra-indicating factors while new ones are made of MR-compatible non-magnetic titanium composites. The same applies to MR-compatible DBS (Deep Brain Stimulus) electrodes. My goal was to evaluate effectiveness of titanium clip cerebral aneurism treatment by MR imaging. Further I purposed to determine: what methods are the most appropriate on 1 Tesla field MRI to diagnose patients after DBS implantation as well as determine safety factors of such examinations.
- CSF flow can be imagined by MR methods. In hydrocephalus cases liquor flow functional analysis and morphology (venrticular dilatation) imaging can be paralleled thus pre-operative diagnostics are more established and post-operative intervention efficiency evaluation is

more proven. Further, my objective was to obtain clinical methods which could be introduced and applied by other neurosurgical institutes.

- Our work hypothesis was that effectiveness of endoscopic neurosurgical interventions could be improved using MR imaging methods. My goal was to plan appropriate MR imaging protocols for neuro-endoscopy treatments.
- Our further work hypothesis was that CT-guidance of spine surgery intervention is possible. For that purpose my goal was to determine the most suitable CT examination protocol.
- Less invasive brain interventions could be planned by adequate frame-based of frameless MR or CT navigation. Considering local co-operation between University of Pécs Medical School, Neurosurgery Dept. and Pecs Diagnostic Center I intended to prepare examination protocols also applicable at other Hungarian medical institutes planning to introduce similar interventions.
- Morphologic CT and/or MRI exams are established targeting methods for functional neurosurgical interventions (e.g. treatment of coordination disorders or pain). My goal was to find best advisable imaging methods and safe neuro-radiology navigation tools for such tasks.
- Fusion of morphology and functional MR imaging results support surgically safe interventions at eloquent brain locations - our team at the University of Pécs Medical School, Neurosurgery Department planned to introduce such fusion-imaging methods as first domestic application. My objective was to establish appropriate imaging procedures for local conditions as well as for possible application in other Hungarian surgical workplaces.
- Three-dimensional CT reconstruction can support optimal surgical intervention planning for spinal evolution disorders. My goal was to prepare suitable 3D imaging protocols and to determine their clinical usefulness.
- Success of surgical epilepsy interventions is mainly influenced by exact localization of epilepsy focus. Neuro-radiology imaging can help these interventions by ascertaining hippocampus atrophy or sclerosis - most typical morphology symptoms - and determining their grade and laterality. Together with my colleagues we introduced routine hippocampus volumetric imaging and established "normal control" values for our (Hungarian) MR laboratory

2. Brain Tissue Water Content (Brain Edema) Quantitative Measurement Water Content Map Method

Measurement of longitudinal NMR relaxation (T_1) is of great importance during MR imaging because results can be correlated with appropriate conversion to water content thus objective data can be acquired on disorders related to liquor room changes.

2.1. Materials and Methods

As first part of the experiment we measured in vitro nine (9) different aqueous dilution samples of MR contrast agent Gadolinium-preparate (MR CA sample phantom) regarding their T1 relaxation time and corresponding measured time values between 530 msec and 2580 msec to normal and edematous brain tissue T_1 values at 1 Tesla field. We measured T_1 values for the Gd-preparate samples in Bruker Minispec PC 140 NMR (Bruker, Germany) equipment at 40 MHz proton frequency and for comparison on a whole-body scanner Magnetom Harmony (Siemens, Germany) at 42 MHz with standard imaging head-coil. During this study we used Inversion Recovery Spin Echo (IRSE) sequences where TR/TE were 2500/12 msec while TI values were chosen as 200, 450, 600, 1000 and 3000 milliseconds. Slice thickness was 10mm with 128x128 imaging matrix resulting 32 minute total imaging time. We repeated our measurement also with inversion-prepared turbo-FLASH technique where TR/TE were 10000ms/1.4msec, averages 2 and nominal flip angle was 3° (other imaging parameters - including TI time values - were identical).

With approval of the University of Pécs Regional Research Ethics Committee we measured nine healthy volunteers (3 female 6 male average age 28 ± 1.3 yrs) experimental MRI protocol as follows: MR imaging protocol of a representative slice in brain region 10 mm above the intercomissure plane, MRI sequence IR prepared Turbo-FLASH with identical parameters as above mentioned for the in-vitro Gd-preparate phantoms. Additionally, images with 4 averages were collected also to examine effect of increased signal to noise ratio (SNR) on T_1 measurement accuracy.

Data processing

MatLab software was chosen for processing of images with different inversion times obtained with inversion prepared turbo-FLASH and T_1 maps were produced by fitting the intensities pixelwise into the following function. T_1 values were determined also from IRSE image data set. According to publication of Fatouros et al. (1999) brain tissue water content map was generated from T_1 value matrix using following equation:

$1/W = 0.935+0.283/ T_1$, where W is water content

Regions of interest (ROI) were drawn on the T_1 maps and transferred to corresponding water maps obtained from the volunteers' brain. Normal T_1 values and brain W's were determined in the standard anatomical brain slice mentioned above (10 mm above intercomissural plane) in different regions including anterior gray and white matter, head of the caudate nucleus, putamen, thalamus, and posterior gray and white matter. Unpaired t-test was applied to point out significant difference between T_1 values of frontal gray/white matter and posterior gray/white matter, respectively. Data are expressed as mean ± standard deviation values.

2.2. Results

Phantom experiments

T_1 values of Gadolinium-preparate samples determined with IRSE and inversion prepared turbo-FLASH showed a very good correspondence with those obtained with spectroscopic method. Only minimal deviation of data points from this theoretical correlation line can be observed only for T1 values larger than 1500 ms. It should be noted that nearly the same accuracy was achieved with turbo-FLASH measurement in 2 min as with the spin echo experiment in 32 min.

Table 1 - Regional T_1 and Water content values compared to Reference (1)

Region	T_1 (ms) NA = 2	T_1 (ms) NA = 4	Water cont.. (%)	Water cont (%) Fatouros P, Marmarou A (1999) Reference (1)
Frontal gray matter	930 ± 50	925 ± 56	79 ± 1.1	
Frontal white matter	492 ± 20	496 ± 17	64.5 ± 1.3	68.7 ± 1.0
Posterior gray matter	823 ± 78*	819 ± 76	76.4 ± 1.9	
Posterior white matter	550 ± 23**	542 ± 24	67.1 ± 1.1	69.6 ± 1.1
Head of caudatus	935 ± 75	929 ± 75	78.3 ± 1.7	80.3 ± 1.1
Putamen	625 ± 49	621 ± 47	70.5 ± 1.9	
Thalamus	761 ± 48	755 ± 46	74.7 ± 1.4	75.8 ± 1.2

T_1 values were established by 2 or 4 measurement averaging
* $p < 0.005$, unpaired t-test vs. frontal gray matter
** $p < 0.001$, unpaired t-test vs. frontal white matter
NA: number of averages applied

Using 4 averages instead of 2 increased signal-to-noise ratio (SNR) as expected. However, the increased SNR did not yield more accurate results in the T_1 measurement than those with 2-averages measurements.

2.3. Discussion

Quantification of T_1 and W values provides an unique tool to follow in vivo the therapeutic attempts in some brain diseases as e.g. malignant brain oedemas. In contrast to lengthy T_1 measurement in a in-vitro solutions, human examinations must remain within a reasonable time. Spin-echo measurement requiring more than half an hour examination time would lead to undesired motion-artifact and long time measurement tolerability is questionable.

Results of human brain MR measurements at 1Tesla field have good correspondence with results of Fatouros and Marmarou who got their results in much longer examinations. Measurement parameter adjustment may yield increased accuracy, but there is a trade-off between signal-to-noise ratio and measurement time.

Early attempts to determine brain tissue water content were done by CT exams and Hounsfield-unit changes where these non-calibrated methods accurate measurements are less possible and repeated CT scans represent disadvantage of increased X-Ray exposition dose. Developments in MR imaging theory (T_1, T_2 and spin density) where the first two methods exhibit good

correlation with brain tissue water content and does not influence magnetic homogeneity and doesn't need special calibration.

2.4. Conclusions

We confirmed that inversion-prepared Turbo-FLASH MR sequences in 1 Tesla field common whole-body scanners are suitable for accurate T1 measurements within reasonable 2 minutes examination time and are able to determine brain tissue water content and water maps. With this recommended method such measurements can be achieved with common MRI sequences in other institutes, too. Follow-up of diseases (and their treatment results) influencing brain tissue water content due to oedematic changes are of great clinical importance. Our method describes above is considered to be proven as appropriate for edema assessment.

3. About MR Compatibility of Intracranial Implants

With the advent of MR imaging technologies new demand arose for MRI compatible implants which do not exclude later MR examinations of involved patients. Further, these devices should be reliable regarding patient safety and minimally affect the magnetic field homogeneity.

One of our *main research goals* was to analyze and determine MR safety and compatibility (possibility of safe post-op MR imaging) of metal clips which play key role in intracranial aneurysm treatment.

Another target research area was to judge 1 Tesla MR examination possibility of deep brain stimulus (DBS) electrodes used in treatment of certain brain-related motion disorders. Despite the importance of safety aspects there were only 1.5 Tesla MR compatibility and safety data available for DBS devices. A complication experienced at another 1 Tesla MRI site - expanding haemorrhage around DBS electrode after MR examination - warned us and inspired a more scientific approach to consider MR safety and compatibility of DBS implants.

3.1. Materials and Methods

3.1.1. To determine vascular metal-clip induced CT artifacts we arranged phantom measurements where we examined *in-vitro* CoCrNi-composite "Phynox", stainless steel alloy and two types of titanium clips attached to a bony skull model both in MR and CT scanners. We used proton density and T_2 and T_1 and Spin-echo MR sequences, further T_1 weighed gradient echo FLASH protocols.

After these phantom-imaging experiments we implanted titanium clips in 21 patients and conventional phynox clips in 17 patients to close aneurysm malformation. Titanium-clip implants were analyzed with proton density and T_2 and T_1 weighed spin-echo MRI sequences at 1 Tesla field (Siemens Magnetom Impact) and we had run post-operative 3D TOF type MRA protocols, too.

3.1.2. In another series we examined 34 DBS implanted patients in MR scanner after having received detailed information and instruction on examination purpose and possible risk and having signed standard official consent protocols. In this group

of patients 16 subjects had unilateral and 18 individuals had bilateral electrode implants. Treatment indication was in most cases (n=24) Parkinson-disease while essential tumor (n=6) was the indication at 6 subjects and primer generalized dystonia indicated DBS treatment for two patients, further there was one patient treated with SM and one patient with tremor of unknown origin..

For MR imaging we used 1 Tesla Magnetom Harmony scanner (Siemens, Erlangen/Germany), keeping the sequence number as few as possible. To analyze electrode position we applied 2 mm gapless T_1 weighed MPRAGE sequences (parameters: TR=2120 ms, TE=3.92 msec, inversion time =1100 ms, flip angle:15°, SAR=0.038 W/kg, gradient slew rate = 19.87 T/second. Depending on clinical setting further T_2 weighed measurements followed (parameters: 6 mm slices with 0.9 mm gap TR=5000ms, TE=85ms, flip angle=180°). For these exams SAR (specific adsorption ratio) was kept as low as 0.1968 W/kg.

All MR scans were post-operative where imaging followed IPG implant intervention by a period ranging from 2 weeks to one year. We checked impedance of the DBS electrodes and we programmed and switched off impulse generators as recommended during MR imaging. All patients were done in full consciousness and a detailed questioning followed each scan to assess relevant side effects. Further, post-scan impedance measurements checked all active electrodes comparing results with pre-scan values. We applied paired t-test for statistical analysis.

3.2. Results

3.2.1. In-vitro phantom CT scan experiments on phantoms with various metal clips led to obvious results: in CT imaging titanium clips were more "transparent" than cobalt-based phynox alloy devices with higher specific density (Ti = 4.43 g/cm³ while Co-alloy = 8.3 g/cm³). Similarly, in MR scanners - during all type of sequences - titanium devices caused definitely less artifacts and imaging distortions around the implant location. During patient scans, despite signal loss immediately at implant location, we could analyze surrounding brain tissue relatively well. In contrary to this, on MR angiography images vessel contours around the clip were less definite and featured flow-drop-out like phenomenon thus judgments about possible disorder re-appearance were impossible.

Clinical examinations found no significant difference between patient groups with titanium and phynox-alloy clips. We couldn't detect difference in results with statistical methods (shi-square method).

3.2.2. Patient with DBS implants did not report unusual sensation during MR scans and there was no significant difference in. Electrode impedance did not changed significantly after MR exams. DBS implanted patients didn't report any unusual sensation neither during MR scan nor after it and there was no change in electrode impedance before and after the MRI examination. Finally - based upon UPDRS motion scale inspected at the patients - we've found no alteration in DBS efficiency after the MRI imaging.

3.3. Discussion

3.3.1. MR imaging has established itself as indispensable diagnostic modality having advantages also in intracranial implant techniques. Beside main biological

compatibility features as stability and flexibility and durability, implants permanently attached to living human tissue should be MR safe and compatible, too. Implanted device must allow MR examination without risk to the patient bearing it. Additionally, for intracranial clips it's an important aspect how seriously an implant disturbs MR imaging and diagnostics in its surrounding Two main effects cause artifacts formed around metal implants on MR scans. First, a local field homogeneity interferes with the image gradients and leads to regional deviations in resonance frequency. Second, eddy currents caused by gradient switching occur in the highly electroconductive material. Both likewise lead to local magnetic field inhomogeneities. In ferromagnetic materials, already relatively weak external magnetic fields cause sharp increase in magnetization; which will not increase proportionally by field strength. At 1 Tesla magnetization in ferromagnetic metal items is approximately 800 times greater than that of non-ferromagnetic objects. CoCr-based phynox alloy clips feature excellent flexibility while titanium devices are recognized of their better biocompatibility property. None of these materials is ferromagnetic but both are electrically conductive metals therefore we must take in account considerable artifact effects. There were no surgery technique differences observed using these two kinds of clips. Although for titanium material clips post-op MR angiography images were good, non-invasive MRI wasn't appropriate method to estimate aneurysm closing efficiency method due to artifact effects in clip surrounding.

3.3.2. DBS is widely used in treatment of certain motion coordination deficiencies. Neuro-stimulator and its electrodes with wiring can interfere with strong magnetic fields and changes in MR scanners and may cause potential risk to the patient under examination with such implants. Most risky effects are warm-up and electrical current induction, dislocation of DBS components and unwanted alteration or loss of generator program. Former guidelines and recommendations referred to 1.5 Tesla MR scanners. Such scanner was not available in the institute therefore, based upon theoretical considerations we've examined patient with DSB implants with adequate caution at 1.0 Tesla field reasonable, too.

Our considerations were as follows: First, 1 Tesla static magnetic field exerts less rotating moment and linear forces on implanted DBS system than a 1.5 Tesla magnet should effect. Second, exiting radio frequency difference at 1.0 Tesla means less SAR (specific absorption ratio) RF energy than higher frequencies used at 1.5 Tesla MR imaging. Third, as gradient changes (slew rate) may induce potentially risky currents in electrodes and their wiring, we limited the gradient change (slew rate) in 20 T/sec to reduce these induction effects. Additionally, RC resonant coupling (antenna effect) reacts onto implanted generator and wires with electrodes causing warm-up. As ^{1}H Larmor frequency for 1 Tesla field is lower than that of 1.5 Tesla scanners and resulting wavelengths are respectively different for the two field strengths, warm-up is more probable at 1 Tesla field.

Based upon the considerations discussed above, we've found that MR imaging of DSB implanted patients is adequately safe at 1.0 Tesla field when all safety precautions are observed.

3.4. Conclusions

3.4.1. Analysing intracranial clip MR safety and compatibility features we've found that titanium clips have less artefacts but still prohibit evaluation of aneurysm

closing intervention efficiency by non-invasive MR imaging methods. The resulting clinical requirement to find an appropriate (i.e. surgically perfect and additionally MR safe and compatible) material for aneurysm clips is still only partially met in the last decade of our experience: while clip titanium material did not changed, endovascular spiral aneurysm closing techniques mean revolutionary development. These intravascular devices - probably due to their aneurysm-filling round shape - cause only minor local artefacts and enable evaluation of aneurysm closing intervention efficiency by MR angiography methods.

3.4.2. MR examination are considered to be MR safe at 1.0 Tesla scanners for DBS implanted patients when implants are checked thoroughly by measuring electrode impedances (proving unbroken intact state) choosing appropriate MR coils and limiting SAR energy values and keeping MR scans as short as possible. Important factors are the generator's switched-off state and position of the implanted generator.

We have found that there is no ideally perfect safety - but we must approach it considering results from implant manufacturer's in vitro phantom measurements and recommendations.

4. Morphology Methods for Hydrocephalus Examination and Functional Analysis of Liquor Flow

Depending on dynamics of the obliteration process, blockage of regular CSF flow (lateral ventricles → foramina of Monroe → III. ventricle → aquaductus → IV. ventricle → foramina of Luschka & foramina of Magendie) and hindering liquor access to extracerebral liquor rooms may cause dangerous conditions. MR imaging is considered to be ideal method for morphology examination. Additionally, we intended to demonstrate that flow-imaging technique could support both pre-operative diagnostics yielding appropriate intervention indications and post-operative evaluation of intervention efficiency. Flow imaging can help actively support selection of surgery solution (choosing ventriculotomia - artificial ventricle break-through by endoscopy instead of previously common shunt implants) and can objectively prove re-established flow through artificial openings.

4.1. Clinical base and methods

We reported about our initial observations analysing treatment and examinations of seven patients. Occlusions of various etiology and grade were indicated usually by CT scans followed by MR imaging on 1T scanner (Magnetom Impact (Siemens, Erlangen/Germany. After having measured T_2 and proton density axial slices and T_1 weighed images in sagittal and coronal planes, FISP and PSIF 2D sequences acquired image data on liquor flow in oblique sagittal and coronal planes. Additionally these images were used to support optimal planning of endoscopic intervention.

Interventions were prepared and executed by CRW strereotactic frame, marking targets by CT or MRI diagnostic localisation using frame support points (location at middle of foramina Monroe and in front of corpora mamillaria) Stereotactic planning yielded localisation as well as intervention route. In OR intervention path and co-ordinates were calculated using stereotactic frame data and Radionics software calculations. Endoscopy intervention followed,

preparing an artificial opening on bottom of III and yielding pathway to extracerebral liquor rooms.

4.2. Results

CT and MRI examinations indicated in all cases obliteration hydrocephalus while liquordynamic analysis evidenced loss of CSF flow through aqueductus and ventricle IV exits, in other locations flow analysis detected flow direction and intensity.

Intervention succeeded without symptom bearing complication, in one case a haematoma of less than 10 mm diameter appeared in the access channel.

Post-op MR flow-imaging has proven for all patients re-established liquor flow at the bottom of ventricle IV. To check MR flow imaging reliability, during our first intervention series we confirmed these results by means of ventriculography (with intra-operatively administered contrast agent) method.

Except one case, intervention efficiency was proven by significant and rapid improvement of patient condition.

4.3. Discussion

As solution in obliterated hydrocephalus cases, ventriculostomy surgery techniques - invented and introduced as early as in the 1920'ies - have regained importance with CT and MRI examination techniques. A combination of stereotactic and endoscopy techniques contributed to efficiency, keeping interventions minimally invasive. Imaging modalities can detect flow deficiencies and their morphology consequences, appropriate liquor dynamic analysis is able to represent pre-op and post-op flow conditions.

4.4. Conclusions

In favour of the patient, neurosurgical methods without artificial implants should be preferred. Beside previously usual shunt-implant surgery interventions - treating obliterated hydrocephalus cases - ventricle III ventriculostomia represent advantageous and efficient alternative. MR imaging successfully supports method indication and patient selection. Functional flow analysis helps post-operative evaluation of efficiency, checking throughput of the artificial opening.

5. Support of Endoscopic Neurosurgical Interventions (Cystic and haemorrhage cases)

Intracranial endoscopic interventions can be considered as solution in treating malformation in the ventricle system or propagating into ventricles. Endoscopy interventions help to minimize operational exposure and related complications. Imaging methods delineate disorder extension additionally support intervention decision with very accurate ex-ante planning of all operation details considering many factors.

5.1. Clinical base and method

CT and MR imaging findings supported three cases of suprasellaris arachnoidalis cyst in pre-operative phase with diagnosis setting and with planning of endoscopic cyst-opening intervention. In post-operative phase morphology and dynamic flow-analysis MR examination yielded result to evaluate intervention success.

In one case of intraventricular haematoma blockage of liquor-passage disorder was confirmed by CT scans. Based upon CT images, precise intervention planning followed and intervention with two rigid endoscopes removed the

haematoma. Residual minimal haematoma was proven by post-op CT scans, additional flow-sensitive MR sequences helped to evaluate post-op liquor dynamic conditions.

5.2. Results

As result of intervention, arachnoidal cysts collapsed and MR confirmed adequate liquor-flow through cyst wall. Overall clinical improvement was observed in all cases.

Except of some residue, removal of the ventricular haematoma was successful and clinical status improves definitely and rapidly due to re-established liquor passage. Results were proven both by morphology and dynamic liquor imaging.

5.3. Discussion

Endoscopy is a suitable method either with two intervention endoscopes - controlling each other - or, with one rigid endoscope in simple cases as e.g. cyst punch and may improve clinical condition or even result in recovery. Morhpology image analysis and image guidance are necessary tools are in pre-operative phase while functional flow imaging can confirm clinical improvement after interventions.

5.4. Conclusion

Endoscopic techniques have limited access to intracranial space but contribute very usefully to treatment of ventricular disorders. MR and CT based imaging and stereotactic targeting support intervention preparation and increase pre-operative safety of such endoscopy interventions while stereotactic guidance enable precise access to intervention locations. Beside morphology diagnostics in axial plane images flow-sensitive MRI techniques help to evaluate liquor dynamics thus effectiveness of the intervention.

6. Imaging Assisted Spine Interventions (CT Guided Biopsy Vertebroplastica and kyphoplastica)

Traditional radiology support of spine interventions started with XRay fluoroscopy imaging when radiologist and surgeon calculated planned intervention site and marked the location on the skin surface. With the advent of CT examinations it is possible to plan many parameters in advance - location, direction and depth - then take the biopsy sample with appropriate device in controlled manner. In the next phase CT examinations provided already therapy support: in vertebroplastic and kyphoplastic intervention cases. Today practice enables the fusion of previously scanned CT or MR images with XRay i.i. acquired images in OR supporting true surgical navigation immediately.

6.1. Clinical base and methods

As radiologist I implemented CT guided spine-biopsy with patient in prone position after skin disinfection and isolation using local anaesthesia. In the first step base-CT images were acquired of the region of interest in cranial and caudal directions. Target tissue location could be marked relatively easily on these images while exact slice and table positions were well reproducible. Planning an optimal access to the target tissue, we determined penetration point, access angle and required depth parameters. Biopsy probe puncture followed and repeated CT scans of relevant slices controlled the step-by-step operation, checking the right direction and depth. Releasing the sharp puncture biopsy device in appropriate distance

from the target point sample was taken. Once probe was pull back we checked possible effusion with a few follow-up CT scans.

We conducted v*ertebroplastic* interventions in neurosurgery OR (with one exception when CT and fluoroscopy image intensifier were applied simultaneously in CT laboratory). Main patient group suffered osteoporotic vertebrae compression and others with tumor and haemangioma indications were treated by injecting bone-cementing material to reinforce affected bone tissue and to alleviate pain. Pre-operative CT and MR imaging helped to determine intervention direction and to decide whether one or more access channels are needed to apply cementation.

During *kyphoplastic* interventions collapsed vertebrae was punctured with the device then a high-pressure balloon (withstanding pressures up to 40 bar) was inflated to align the compressed vertebrae. Usually, already pressure around 10 bar was enough to raise vertebrae into original position. A two-component bone-cement was applied in this cavity, correcting both height and kyphosis angle. Neuro-navigation system guided the whole intervention, pre-op CT images with stereotactic frame were merged with OR taken XRay fluoroscopy images thus establishing maximum safety and exactness for real-time intervention control.

6.2. Results

We experienced no complications after CT guided biopsy probes, in 80% of all cases the sample taken was appropriate for conclusive histology diagnose.

There were no misalignment or guidance failure cases at vertebroplastic interventions. We used visual analogue scale (VAS) to assess clinical efficiency of operation where we confirmed an average improvement of 55%. Theoretically, bone-cement material applied for vertebroplasty can overflow and may cause epidural expansion and heating. Nevertheless, we experienced no neurology symptom development, not even in those cases where we observed minor extravertebral cement protrusions on fluoroscopy and CT images. Height and kyphosis correction wasn't accomplished in these cases.

Kyphoplastic technique compensates two deficiencies of vertebroplastic interventions: compressed vertebrae can re-gain its original height and also kyphosis angle could be decreased. Primary goal is alleviate pain, where we confirmed results corresponding to visual analogue scale evaluation (pain complaints of affected patients decreased from 93% to 48%).

6.3. Discussion

CT guided biopsy interventions cause less stress to the patient due to smaller device sizes and are feasible in local anaesthesia, too. Using CT scanner for direct guidance caused intermittent procedure flow (intervention outside, imaging inside the CT gantry) and required unusually long intervention time (more than 30 min), definitely longer than conventional diagnostic CT exams.

We can confirm that after having done large number of vertebroplastic interventions, in introductory phase CT and MR imaging contributed successfully to safe OP preparation. Later on with growing case number and surgery experience initial elaborateness wasn't necessary any more.

Neuro-navigation supported kyphoplastica combines two modern methods to achieve maximum safety and efficiency of interventions. Ability of image guidance is indispensable presupposition facilitating controlled localization.

6.4. Conclusions

The evolution processes discussed above - image guided spine interventions - have grown more and more sophisticated and complex. Different modalities and techniques contributed to this evolution while importance of imaging guidance support remained unchanged. Additionally, neuro-navigation merges various imaging techniques - and images of different origin - to achieve maximum intervention efficiency and safety.

7. Localization of Functional Neurosurgical Targets (lesions, DBS) Frame-based Trajectory planning

Disorders on any level of somato-sensory system may lead to neurogen pain development. In cases not treatable by medication, thermo-coagulation in thalamus posteromedialis centers may lead to permanent and complete pain relieve.

In Parkinson-disease and various dystony and tremor cases - when long-term appropriate medication is unsuccessful or impossible - targeted thermo-coagulation of certain pallidum and thalamus core regions lead to significant clinical improvements.

Beside the above described methods - based upon targeted destroy of core tissue regions - a new technique of DBS implantation has evolved in recent decades. Similarly to cardiac pace-makers permanent electrodes implanted into deep brain stimulate core regions. In previous chapters we described MR safety aspects of such DBS electrodes, in this chapter we'll discuss importance of targeting precision.

Neural core regions represent tiny target points in closed intracranial room. To achieve symptom improvement exact and coordinated targeting is needed, reducing the probability of unwanted side-effects as partial paralysis or seeing disorders. Target points in core regions are of empiric nature and must localized on MR images and should be accessed in neurosurgery OR guided by stereotactic methods combined with electrophysiology measurements.

7.1. Clinical base and methods

7.2.

Our first domestic report on MR-guided ablative thalamotomy interventions (aiming neurogenic pain alleviation) we summarized criteria for intervention. Based upon this criteria - systematic complaints and nervous system symptoms with typical pain character - we can select patients for those neurosurgical treatment is indicated. At least two consecutive month of unsuccessful conventional anaelgetic and additional antidepressant and antiepileptic medication should precede intervention decision. Pain was measured and evaluated both pre-op and post-op settings on visual analogue scale (VAS). Our first publication reported 7 cases treated with ablative thalamotomy intervention.

Thoroughly prepared and exactly positioned MR imaging on 1 Tesla Magnetom Impact (Siemens Erlangen/Germany) was the initial key point for the procedure. Patient head was caged in CRW stereotactic frame, in this fixed position precise plane alignments was necessary to avoid asymmetry errors. 2 mm MR image

slices were measured in a plane aligned to anterior and posterior comissure. As next step we selected required core area target point on slices laying in the intercomissure plane. Intervention followed in neurosurgery OR with stereotactic frame still mounted, Radionics software calculated target coordinates during the intervention. Pain-opposing treatment was achieved by point stimulation with bi-lateral impedance check. During the procedure, first reversible, then in optimal situation irreversible thermo-coagulation followed at 75-80 °C centigrade in the medial thalamus core points. This method results in RF thermo-coagulation lesion regions ranging between 40 and 120 mm^3.

We reported in separate articles about ablative interventions applied for motion-disorder correction (i.e. inducing defined brain core group lesion) and treating Parkinson disease, further tumors of various etiologhy and dyskinesis cases. Pre-operative MR imaging was common for all these interventions where targets were selected based upon previous successful ablation experience. Target point selection was as follows. Parkinson disease: in globus pallidus pars internus (Gpi). Essential and post-traumatic tremor cases (not treatable by medication): thalamus nucleus ventralis intermedius (Vim).

DBS implant points resulting from MRI targeting examinations described above were as follows: for Parkinson disease patients: subthalamicus nucleus (STN); For dystnia patients: globus pallidus pars internus (Gpi); Essential and posttraumatic tremor cases: thalamus nucleus ventralis intermedius (Vim). We guided and executed all interventions according to recommendations of the special technique.

7.3. Results

We experienced neither at MRI examinations nor in targeting procedure any disturbing conditions. After post-op follow-up we didn't found any target selection as erroneous.

Our experience is definitely positive regarding treatment efficiency for all three main patient group. Considerable relieve of neurogenic pain was confirmed in all cases, manifesting both on visual analogue scale and in necessary medication, and what's most important: by improvement of patient life quality. Nevertheless, in some cases symptom improvement was temporary only. DBS implant technique introduced new possibilities in these disease groups - but differences between expectations and reality results warn us: DBS is not a miracle method. Neuro-stimulation and neuro-modulation may have unexpectedly positive effect on memory features, too.

7.4. Discussion

Precise imaging and exact targeting are common prerequisites for treatment of a heterogenous patient group (neurogenic pain and motion-coordination disorders) where definitive RF thermo-coagulation (permanent irreversible artificial lesion) or flexible neuro-stimulation with DBS electrodes are used. Only high level routine of well-trained and experienced surgeon and radiologist team can be successful and achieve reliable intervention results in increasingly complex and sophisticated functional brain surgery environment.

Both neurogenic pain and motion disorders affect life quality seriously making normal conduct of life nearly impossible. Even expensive interventions as DBS implants are indicated and reasonable as solutions in these cases.

7.5. Conclusions

Image guided functional brain surgery is possible only in those clinical centers where comprehensive pre-operative sophisticated MR examinations and target planning tools are provided and experienced specialist surgeon team is present. I consider my activity in arranging MR examinations, training of imaging technologists and active partnership in target selection as permanent beneficial result.

8. Morphology Imaging (with Image Fusion) Guided Neuro-microsurgery in Combination with fMRI Treating Disorders in Eloquent Regions (keyhole and epilepsy)

We had reported about our achievements in image-guided micro-neurosurgery ("keyhole craniotomy") more than 10 years ago in domestic publications. Our main goal was at these interventions to remove subcortical cavernomas - visible on CT and MR images - with minimally invasive methods. To achieve our goal we planned stereotactic targeting and surgical intervention based upon targeting results.
Developments in functional imaging - and time - prepared new scientific tools and solutions: functional imaging of surrounding brain tissue regions increase the safety of brain surgery.

8.1. Clinical base and materials

CT or MRI examinations revealed disease cause at four patients with epilepsy where medication was not possible due to cavernosus brain angioma. Cavernomas were present in eloquent areas (2 cases in gyrus precentralis further one in gyrus angularis and one in gyrus temporalis superiorban). CT findings looked like calcification while invasive catheter angiography could not reveal none of these disorders. As symptomatic treatment of epilepsy in 3 cases we decided neurosurgicalgery resection. For 3 patients we planned MR guided, and in one further case CT guided stereotactic intervention with CRW frames and Radionics software coordinate calculation discussed earlier in this paper. In pre-op target selection phase we examined thoroughly pathway of sulci and optimal access route for surgery. During surgical OR intervention we tried to prepare the smallest possible craniotomy (keyhole) then we have re-sectioned subcortical cavernomas. All interventions were followed by control MRI exams as well as post-op epileptic seizure history was tracked.

We conducted the very first experimental functional MRI in 2005 in Pecs Diagnostic Centre, Hungary where functional brain regions were localized on detailed morphology images. True clinical fMRI examinations started in fall 2005 where 50 exams of 18 patients followed in one-year period. This type of functional MR imaging is based on the so-called BOLD effect i.e. blood oxigenation level dependent MR contrast appears on morphology images. Functional brain regions with enhanced neuronal activity show sligth changes

oxy-haemoglobin levels. T_2^* MR signal increases due to this effect in special sequences (BOLD fMRI). Paradigms (cyclic activation and relaxation protocols stimulating certain brain functions) were applied depending on analyzed brain region - we used "word-generation paradigm"(concentrating on words starting with given letter)for Broca's center activation with 50 sec activation and 50 sec relax time. We achieved Wernicke's center activation by alternating active announcement listening and relaxation periods. Motion-related cortex region activation is possible - for cooperative patients - with so called "finger tapping" paradigm (subject repetitively touches his/her fingers) while for less cooperative patients assisting personnel touched fingers of patients under test the same way. ing. In all cases clinically relevant activation paradigm was chosen. Parameters were as follows: TR= 2500 ms, i.e. 20 measurements occurred in 50 seconds then 50 sec relaxation followed cyclically to improve activation enhancement on images. Except for passive finger tapping, all paradigms need well cooperating patients. Interventions were planned so called "frameless stereotaxia" based upon specially prepared morphology and functional MR image overlays. We used Stealth-Station Treon System, Medtronic neuro-navigatiom system for intervention coordinate calculations.

8.2. Results

We could re-section malformations (together with surrounding hemosideric glial barrier to prevent later epilepsy symptoms) successfully in all cavernoma cases with minor operative intervention. We experienced no complications and all cases reported permanent seizure-free lifestyle conditions.

Later fMRI supported intervention (left temporal tumor re-section) at one patient led to temporarily hearing deficiency but leaving speech recognition features intact. Interventions at patients with malformation re-sections in motor cortex region caused no paralytic effects. Follow-up examinations detected no complication while all epilepsy cases featured clinical and symptomatic improvement or at leas were controllable.

8.3. Discussion

Once upon a time... before modern imaging techniques emerged, non-bleeding cavernoma was mainly indication for re-section since cavernomas feature rarely pronounced calcifications detectable on bi-plane X-Ray. On CT and MR images cavernomas often appear as incidental findings, featuring symptom-generating epilepsy in 31%; in 25% of cases with their space-filling effect, in 13% haemorrhage and in 6% as headache. Micro-surgery intervention is the ideal treatment achieving results with minimal exposure and invasion.

As disorder is well observable on MR images targeting is relatively easy and when sufficient experience is given, eloquent region can be accessed successfully considering targeting aspects as sulci pathway etc.

At the time of the article describing keyhole craniotomy (1997) Yetkin established following intervention risk estimation: when distance between malformations and eloquent region is greater than 20 mm, the probability of function loss is low. In contrary, when this distance is less than 10 mm, probability of collateral function damages is 50%. Since the introduction of fMRI methods this former statement has lost validity (Sunaert): diffusion tensor imaging (DTI tractography) results show that not the simple distance is what counts. Bundle pathways have to be determined in all cases individually,

increasing surgery safety. Further, we realized that centers are able to re-locate (transpose) in slowly progressing tumor cases, and brain plasticity can help in retaining or re-establish brain functions. Functional MR imaging can confirm these effects when affected patients are fMRI examined before and results are used to intervention planning. Neuro-navigation using merged morphology and functional MR images may represent optimal operation approach where minimal intervention with less probable side-effects yields maximal efficiency.

8.4. Conclusions

Image guidance supports maximally efficient intervention in both subcortical malformation (e.g. cavernoma) cases and tumor re-section in eloquent regions. In certain cases development makes use of stereotactic frames unnecessary (frameless stereotaxy). Further, functional MRI data may help in intervention path selection. All tools together contribute efficiently to validate the minimally invasive principle is brain surgery.

9. Benefits of 3D CT in Optimal Surgery Treatment of Certain Development Disorder (e. g. Marfan)

Marfan syndrome is a dominantly inherited autosom disease affecting interstitial tissues, and having symptoms mainly localized to the skeleton, the cardiac and circulatory system and the eye. Frequency of spine deformities is near 80% where scoliosis is the leading symptom but vertebrae dysplasia and widening of spinal canal are common, too. Our report describes an unpublished case with need for fast intervention where we discuss the importance of imaging aspects.

9.1. Case interpretation

18 yrs. old female patient (typical Marfan-syndrome with cardiac valve deficiency and ectopic eye and myopy) refused proposal of conventional correction surgery to her double-scoliotic disorder. Beside progressing scoliosis also neurology symptoms appeared (lower limb torpidity and pain)

9.2. Methods

Patient's bidirectional native XRay confirmed L.II-L.III subluctation where deviation in coronal plane reached 15 mm but there were no similar shift in minor joints. Shift between vertebrae L.II - L.IV was 8 mm in the same direction aggregately leading to spine high grade angulation. We measured grade of dislocation objectively on three-dimensional CT reconstruction images. Grade of deviation and neurology symptoms urged reconstructive intervention. Intervention followed, where we achieved 3D correction by fusion of Th.IX-L.V with Cotrel Dubousset device set. This intervention solved the scoliosis nearly perfectly and decrease of subluctation was also successful.

9.3. Discussion

Cause of subluctation in Marfan-syndrome scoliosis is mainly the progressive rotational dislocation. This in turn induces neurology symptoms in higher spine regions caused by medulla spinal compression, in lumbal region caused by cauda

fiber deterioration. Computer tomographic 3D reconstruction facilitated obvious and spectacular analysis with 3D rotation of the spine in virtual space. CT reconstruction findings confirmed progressive rotational dislocation and together with neurology symptoms - helped to indicate urgent intervention.

9.4. Conclusion

X-Ray and axial CT imaging facilitated diagnosis of a previously unpublished serious spine disorder, additional 3D reconstruction of the region of interest helped the intervention indication. Real consequences were fast intervention decision and effective patient treatment.

10. Hippocampus Volumetry in Normal Control Protocols

10.1 Introduction

Still today, MR imaging is the probably best way for exact in-vivo brain anatomy examinations. Exact knowledge about morphology deviations in brain structure play important role in understanding neurology symptoms and their pathology background. Medial temporal lobe is the probably most often volumetry analyzed region. Morphology changes in this region are typical for temporal epilepsy, in Alzheimer disease, in memory disorders or in schizofrenia. Nevertheless, MRI volumetry of certain regions, specially analyzing the size of the hippocampus and amygdala, localizes disorder of that kind with increased specificity and reliability. There is no uniform opinion about the question: how does clinical appearance and grade and progression of the disease correlate with morphology deviations. Methods of volumetry changes significantly site to site in clinical praxis, therefore results in various clinical centers are hard to compare. To reduce deviations caused by method differences C. Watson's established a commonly accepted volumetry protocol (1992). Using this method and the technique available in our institute, we publish here hippocampus and amygdala MRI volumetry data of 40 healthy subjects together with our applied analysis protocol. Our goal was - within an epilepsy surgical intervention program at Neurosurgery Dept. (University of Pécs Medical School) - to assess location and grade of hippocampus atrophy and sclerosis disorders thus help to identify laterality of epilepsy focus.

10.2 Methods and materials

During our data assessment we evaluated MR images of 40 healthy young female subjects (age ranging from 19 to 26 average 21.3 yrs) having previously received information documents about the project and having signed consent protocols. There were no neurology and internist examinations prior to the MR imaging but anamnesis for all subjects excluded neurology diseases or head trauma or any regular medication. MR imaging confirmed no pathology changes at 39 subjects and one person was excluded from later evaluations because of right lateral cerebellaris hypoplasia. Further, we've selected two reference epilepsy patients under year long treatment in the Neurology Department (University of Pécs Medical School) and, after having signed consent protocols, we used their follow-up MRI results for volumetry purposes. Both patients had anti-epileptic (carbamazepine) treatment but no previous hippocampus atrophy

was known in their cases and their there was no hippocampus anomaly to observe on their T2 WI MR images.

MRI examination

We used Magnetom Impact 1.0 Tesla (Siemens Erlangen/Germany) MR scanner. Basic measurements were 40 coronal slices of 1 mm thickness without gap acquired FISP 3D sequences; parameters: TR = 30 msec TE = 0 msec and 1.05mm*1.05mm pixel size (flip angle = 40°, matrix = 160×256). Before volumetric analysis we've set optimal contrast and signal-to-noise ratio individually for each subject to minimize volume assessment errors.

10.3 Measurement organization

For volume assessment we used Mass 40 and Mass 41 MRI Analytic Evaluation Software (Medis, Netherland) running under Suse Linux. We entered MR slices in form of DICOM 8-bit greyscale images into the computer database. During volume assessment we selected hippocampus and amygdala boundaries manually, with mouse controlled contour drawing on each slice individually. A total of six (6) regions were outlined on the MR images: hippocampus and amygdala and cerebral hemispheres on both sides. The software has integrated automatically volume of those structures selected manually and established a 3D computer model of the analysed structure. All measurements and evaluations were executed by two independent observers (K.H. and F.N.).

During volumetry analysis we assessed absolute volumes of right and left hippocampus (JH; BH) and left and right amygdala (JA; BA). Further, we hippocampus and amygdala indices representing differences between left and right lateral measurements. To obtain index value, following equation was used:

$$HI = \frac{|JH - BH|}{(JH + BH) : 2} \times 100$$

Relative volume was defined as proportion number R. For all reference persons a certain part of hemispherum volume was assessed (based on MR images). In this procedure we measured from Monroe's foramen interventriculare in occipital direction on three consecutive slices. To obtain R proportion number, following equation was used:

R = hemispherum volume of control person / average hemispherum volume
Relative volume = absolute volume ×R

We calculated 3D images based on contours drawn on MR images and identified head - body - tail sub-regions of the analysed anatomical object. For all subjects absolute and relative volumes and asymmetry of hippocampus sub-regions was calculated.

Image analysis

For standardization and reproducibility of volumetry assessment we need exact procedures based on accurate and thorough anatomy knowledge. To obtain exact hippocampus and amygdala anatomy boundaries we've studied Talairach, Verlag

and Sobotta anatomy atlas. During procedure definition we used C. Watson's protocol publication (1992) mentioned above.

Amygdala volumetry

We started to draw pole of frontal amygdala on MR image on which Sylvi's sulcus lateralis ends and sulcus endorhinalis sulcus starts. Thus we excluded claustrumot and nucleus endopiriformis from the evaluation. If cases, where the amigdala upper boundary wasn't exactly delineated on MR image, we draw a support line from sulcus enthorhinalis laterally in direction toward fundus of insula lower sulcus, then area below this support line was counted to amygdala substance. Lateral wall of amygdala was determined as upper boundary of lateral ventricle while upper border of hippocampus represented its lower boundary. Medial limit was the sharply delineated grey matter, covering the uncus.

Hippocampus volumetry

Anatomy structures surrounding the hippocampus show very similar signal intensity on MR images therefore we had to define support lines in several regions. We considered regions of propet; gyrus dentatus; fimbria hippocampi belonging to the hippocampus substance but excluded parahippocampal cortex parts and crus fornicis and gyrus cinguli.
Hippocampus was measured to the height level where fimbria hippocampi sharply separates from crus fornicis, or - when we couldn't define this latter exactly - we continued to draw hippocampus substance up to the appearance of comissura posterior.

10.4 Results

Variance between examiner's assessing results were 3% (volume values) and 1,24% (amigdala index) and 0,48% (hippocampus index). Considering the low inter-observer variance, an average of the two observer's measurement was used in all cases.

Hippocampus volume

Analysing hippocampus volume in 39 healthy subjects we've found following volume averages: right hippocampus 2.12 cm^3; left hippocampus 2.07 cm^3. Individual hippocampus volumes differ significantly, relative difference between smallest and largest volumes was 76%.
Total hippocampus volume histograms exhibit normal distribution.

Amygdala volume

Evaluating 39 healthy person's data we've found following amigdala volume averages: right side 1.19 cm^3, left side 1.2 cm^3. Nevertheless, individual amigdala volumes show somewhat larger differences than that of hippocampus (91% vs. 76%). Similarly to hippocampus volume statistics, also aygdala volume histogram shows normal distribution.

Asymmetry indices

HI index represents left and right hippocampus volume differences. HI average was as 3.17%, its value was 9.8% when we increased range by $\pm$3SD. Based on our results greater than this asymmetry may be considered as abnormal. Compating left and right hippocampus indices with paired T-test, $p = 0.3$

resulted, i.e. we've found no significantly larger volume hippocampus, neither on left nor on right sides.
The same evaluation for amygdala asymmetry index (AI) resulted an average of 3.48%, its value was 12% when we increased range by $\pm$3SD. Also T-test did not confirm significant difference between right and left amygdala sides (p=0,31).

Relative volumes

Additionally, we compared individual hippocampus and amygdala volumes to total cerebral hemisphere of the given subject. Unexpectedly, statistics of these relative volume measurements slightly increased individual deviation as well as increased the difference between smallest and largest volumes; but basically did not change the averages found b absolute measurement.

We summarized hippocampus sub-region volume and asymmetry data in Table 2. Regions were identified on 3D hippocampus model images. Anterior third was considered as "head" the middle third as "body" and posterior portion as "tail" as compared to anatomy atlas referred above. Asymmetry averages and SD values for sub-regions slightly exceed those related to the whole hippocampus.

We demonstrate the importance of hippocampus sub-region volumetry evaluation with following example. Visual reading of MR images for a patient suffering in temporal epilepsy indicated possibility of hippocampus atrophy. Volumetry analysis for the same patient provided somewhat greater than normal asymmetry of 15%. Comparison of relevant sub-regions resulted even greater (26%) decrease for left side hippocampus tail - coinciding with EEG detected seizure focus. Hippocampus "head" and "body" asymmetry has shown only slightly greater than normal averages calculated $\pm$ 3*SD values. Consequently, as illustrated by this case, whole region asymmetry is not necessarily proportional to sub-region asymmetry. There is a mathematical probability that total hippocampus asymmetry does not exceed physiology average while there are significant atrophy to observe in one of the sub-regions.
Role of the relative volume calculations will be demonstrated on another example. At a temporal epilepsy patient case, neither MRI results nor volume and asymmetry index calculations indicated lateral hippocampus involvement. Epileptic seizure features and interictal surface EEG results arouse the suspicion of bilateral independent temporal epileptic foci. Indeed, relative (hemisphere volume referred) volume calculations indicated symmetric abnormal bilateral decrease (50%) in hippocampus size and confirmed atrophy involvement at this patient.

Validation of Volumetry Measurements

As reference we determined volume of a sphere phantom with known radius both mathematically and with MRI volumetry. We compared results from the two measurement methods to validate our MRI-based volumetry protocol. MRI volumetry data demonstrated slight deviation of 4% in average relative to theoretical volume calculations (9.07 cm^3 vs. 9,52 cm^3). Thus, the tolerance of our volume measurement is approx. 3….5%. This order of magnitude in measurement error shows that hippocampus size anatomy object's absolute volume can be measured with good confidence without corrections.

10.5 Discussion

With introduction of hippocampus and amygdala MRI volumetry measurement standards in our institute we defined normal ranges for these structures and analysed measurement validity and reproducibility. Volumetry data published in international literature show significant differences. Therefore, we can conclude that hippocampus and amygdala normal volumes are strongly measurement dependent with considerable deviations. Anatomy borderline definition, imaging technique differences, sample heterogeneity all could be sources of deviations. For diagnostic purpose it's essential for all institutes to elaborate own standardized volumetry procedures based upon international recommendations. According to our information present writing is the first Hungarian publication hippocampus and amygdala volumetry examinations. Values for normal subjects measured in our institute in the last 12 years are nearly in the range of international publication data. To avoid age sex and race caused deviations we selected subjects of nearly same age and same sex. It is a known fact that hippocampus size decreases with age. Since age referred volumetry evaluations are still missing in the international literature, age correction data aren't available. This method supports mainly young epilepsy patient's pre-operative examinations therefore we consider the method useful in hippocampus involvement detection. According to our present knowledge, lateral asymmetry is age independent; it correlates rather with disease period length and frequency of seizures. Thus asymmetry results seem to be appropriate to lateralize epileptic focus without correction.
Reliability and reproducibility of our method is demonstrated by minimal variance between results of two independent reader, further the coincidence of MRI volumetry data with mathematical phantom sphere volume calculations. We intended to increase measurement exactness choosing 1mm MR image slices without gaps. For thin slices the signal-to-noise ratio (SNR) is poorer thus differentiation of relevant structures is more difficult. Therefore, we introduced standard "support line" technique as described above. According to publication of Laakso et al. increase of slice thickness upto 5 mm improve SNR and does not influence measurement accuracy significantly. Therefore we plan to introduce 3 mm slice thickness MR acquisition for volumetry purposes. There are not too much publications about hippocampus sub-region analysis. Clinical aspects of atrophy in hippocampal regions are not yet analysed. Our case-based sub-region evaluation aims clarification of clinical aspects and may help to indicate possible hidden, on sub-region restricted atrophy. Nevertheless, involvement of sub-regions increases measurement error - probably due to smaller sub-region geometry. Therefore a common evaluation all volumetry data is recommended.

We esteem relative, hemisphere-related volume calculations also important since bilateral atrophy cases are identifiable with this method. Volumetry procedures are time consuming but more and more evaluation software support automatic segmenting process independently of radiologist reader person, increasing speed accuracy and reliability of results. Well-based anatomy knowledge is still indispensable to check automatic anatomy border selection.

11 Summary of Results

- We've worked out and introduced as first publisher in Hungary the objective measurement of cerebral water content by MRI water-maps
- We elaborated as first institute in Hungary MR-guided biopsy and functional neurosurgical intervention methods
- As first institute in the country we introduced CT/MR-guided III.ventricle ventriculostomy
- I was among the first Hungarian professionals to conduct CT-guided spine biopsy
- Our institute accomplished the first Hungarian MR comparative imaging with titanium clip implant
- As first researcher, we confirmed safety of DBS implants at 1.0 Tesla MR field
- As first institute in Hungary, we established procedures for image-, and fMRI-guided micro-neurosurgical interventions
- We elaborated 3D CT imaging of lumbar subluxation at Marfan-syndrom patient
- We were the first institute in Hungary determining hippocampus normal volumetry data

12 Acknowledgements

Specifying all those persons who helped my activity, first of all I'd like acknowledge to Tamás Dóczi for his support. His encouraging incitement moved my professional work in the last 16 years and contributed essentially to the foundation of Pécs Diagnostic Center. The same way I am thankful to Prof. Dr. Gábor Vadon, Diagnostic Center late director, and to Mr. Béla Németh, managing director since the beginning of the Center. I am saying warm thanks also to Prof. Dr. Sámuel Komoly for his attention originating from common university scientific collegium experience. Thanks for his and encouragement to my scientific summary resulting PhD thesis helping to opening new period in my professional life.

I'd like to mention all my colleagues who deemed me worthy for support and contributed with co-operation, experience and information: first of all Attila Schwarcz, István Balás, Norbert Kovács and Krisztina Horváth, Ferenc Nagy, Zsolt Illés, Gábor Kasó, Zoltán Horváth, Ferenc Vető, András Büki, István Domán, Carlos Llumiguano and István Mészáros. I'm thankful to all other colleagues standing by, assistants and technologists where the help of Tamas Vajna was especially useful.

What's most important comes at last: I'm sending my sincere thanks to my dear wife Mária Garamszegi assuring joy and harmony as true companion for my family and professional life. Full-hearted thanks also to my children Andras and Anna fulfilling our life's mission on Earth.

Abbreviations and Index

MRI – Magnetic Resonance Imaging
SE – Spin Echo
GE v. GRE = Gradient Echo
IR – Inversion recovery
TI –Inversion Time
TR – Repetition Time
TE – Echo Ttime
FA – Flip Angle
FLASH – Fast Low Angle Shot
MPRAGE – Magnetisation Prepared Rapid Gradient Echo
FISP – Fast Imaging with Steady State Free Precession
PSIF – Reverse Fast Imaging with Steady State Free Precession
SAR – specific absorption rate
RF – radio frequency
PET – positron emission tomography
CT – computer tomography
3D CT – 3 dimensional computer tomographic reconstruction
GPS - Global Positioning System
CRW- Cosmann-Roberts-Wells stereotactic frame system
Frameless – stereotaxy without use of external frame
LINAC – linear accelerator
IGRT image guided radiotherapy
DBS – deep brain stimulator
VAS – visual analogue scale
UPDRS - UNIFIED PARKINSON'S DISEASE RATING SCALE