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Original Research Article

MAGNETIC RESONANCE IMAGING-BASED ASSESSMENT OF INTERNAL CAPSULE MORPHOMETRY AND DIFFUSION CHARACTERISTICS: A RETROSPECTIVE STUDY IN SOUTH INDIAN ADULTS WITH NO NEUROPARENCHYMAL ABNORMALITY

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ABSTRACT

Background: Internal capsule is a white matter, divided into anterior limb, genu, posterior limb, retrolentiform limb (retrolenticular part) and sublentiform limb (sublenticular part). MRI is one of the most efficacious diagnostic modalities, as it provides us with all vital information, which can be unclear or deficient in other conventional diagnostic modalities. **Aims & Objectives:** To evaluate the morphometric dimensions and diffusion characteristics of the internal capsule using MRI in South Indian adults, and their correlation with age and gender.

Materials and Methods: A Restrospective study was conducted amongst 160 normal south Indian adults; wherein Morphometric Analysis and diffusion characteristics of the Internal Capsule was assessed with the help of MRI. All recorded data was analyzed statistically with relevant statistical tests, such as descriptive statistics like mean and frequencies; whereas 't' test was used for comparison between mean of 2 groups, with statistical significance being $p<0.05$.

Results: We recorded the mean internal capsule measurements on the left and right side with detailed measurements as follows: the anterior limb to be 4.09 and 4.21, genu to be 6.15 and 6.30, posterior limb to be 6.40 and 6.66, genu angle to be 117.90 and 118.97, ADC-DWI to be 0.76 and 0.70 respectively.

Conclusion: In our study, we found statistical difference between left and right sides, across male and female gender and across various age groups in patients aged between 30-75 years, except for a few characteristics of the internal capsule. As there is limited literature available with regard to the characteristics of the internal capsule, therefore we advocate more extensive research studies to shed light on the available data, while providing supportive data to the existing literature.

Keywords: Brain, Capsule, Imaging, Morphometric, Magnetic resonance imaging.

INTRODUCTION

The internal capsule is a white matter composed of efferent and afferent fibers arranged in the shape of a fan that extends vertically connecting specific cortical areas to the spinal cord. The internal capsule has been separated into five parts: the anterior limb, the genu, the posterior limb, the retrolentiform limb (retrolenticular portion), & the sublentiform limb.[1-3]

Internal capsule can be influenced by an array of pathologies; wherein it is clinically important to comprehend the morphological structure of such a highly susceptible area influenced by numerous illnesses (degenerative as well as demyelinating diseases, deficiency of vitamins, hemorrhage, arteriovenous malformation, infarction, vascular pathologies like angioma, glioma, oligodendroglioma/ganglioglioma, neoplastic conditions like as neuroectodermal tumor, metastaticcystosis lesions & tuberculosis.[1,3]

It is positioned in the inferomedial region of every hemisphere of the brain, dividing the caudate nucleus along with thalamus away from the lentiform nucleus. The descending and ascending routes that go through the internal capsule link the cerebral hemispheres along with subcortical regions to the brain stem as well as spinal cord.[1-3]

In the last few years, MRI-based morphometric analysis has emerged as a powerful tool for studying the anatomical variations as well as dimensions of particular areas of the brain, offering valuable insights into neurodevelopmental processes, analyzing pathological conditions, as well as forecasting cognitive processes.[4,5]

In MRI investigations of structures in the brain, special attention has been paid to the corpus callosum (CC), a large white matter tract required for interhemispheric interaction.[4]

Magnetic resonance imaging (MRI) represents one of the most effective methods for diagnosis since it gives all critical information that other conventional diagnostic modalities may lack.[6,7]

This study aimed to assess both the morphometric aspects as well as diffusion characteristics (DWI signal along with ADC values) of the internal capsule in healthy South Indian adults, with a special emphasis on age- and gender-related differences. Establishing such normative values may be used as a reference point in clinical and research contexts to assess white matter disease.

Aims & Objectives

- To evaluate the morphometric dimensions and diffusion characteristics of the internal capsule using MRI in South Indian adults, with emphasis on age- and gender-related variations.
- To measure the widths of the anterior limb, genu, and posterior limb of the internal capsule on axial T1-weighted MRI images.
- To calculate the genu angle formed between the anterior and posterior limbs.
- To assess signal intensity on diffusion-weighted imaging (DWI) and calculate quantitative apparent diffusion coefficient (ADC) values in different segments of the internal capsule.
- To analyze and compare the morphometric and diffusion parameters across different age groups and between genders.
- To establish normative reference values for morphometry and average ADC values of the internal capsule in the South Indian adults.

MATERIALS AND METHODS

Materials and Methodology

This retrospective study was conducted at a tertiary care center in Karnataka, Southern part of India, following ethical clearance from the institutional review board. A total of 160 adult South Indian subjects, aged between 18 and 65 years, who underwent brain MRI for non-neurological indications and showed no neuroradiological abnormalities, were included.

Inclusion Criteria

- Healthy adults aged 18–65 years
- Normal brain MRI with no structural abnormalities
- No clinical history of neurological, psychiatric, or systemic disorders

Exclusion Criteria

- Evidence of intracranial pathology (e.g., tumors, infarcts, hemorrhage)
- History of stroke, neurosurgery, head trauma, or seizures
- Systemic diseases affecting white matter (e.g., diabetes, hypertension)
- Poor-quality or motion-degraded MR images

Imaging Protocol

- All subjects underwent brain MRI on a 1.5 Tesla Siemens Magnetom Avanto scanner using:
- Axial T1-weighted images for morphometric assessment
- Diffusion-weighted imaging (DWI) with b-values of 0 and 1000 s/mm²
- Apparent Diffusion Coefficient (ADC) maps automatically generated from DWI
- Parameters included: slice thickness of 5 mm, no inter-slice gap, and standard field of view.

Measurements

- Morphometric evaluation included measurement of:
- Widths of the anterior limb, genu, and posterior limb of the internal capsule
- Genu angle, defined between lines through anterior and posterior limbs
- ADC values and DWI signal intensity for diffusion characteristics
- Measurements were taken bilaterally and analyzed for age- and gender-based differences.

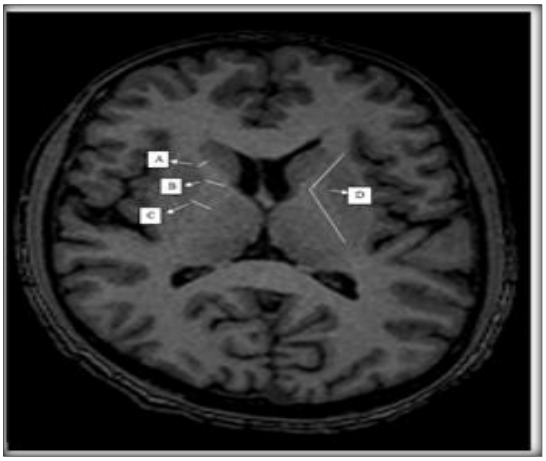

Figure 1: Measurements made in transverse sections. A: width of the anterior limb of internal capsule; B: width of the genu of internal capsule; C: width of the posterior limb of internal capsule; D: genu angle (measured between the lines passing through the middle of the anterior and posterior limbs

Statistical Analysis

All data were compiled in Microsoft Excel and analyzed using SPSS version 26.0. Descriptive statistics (mean ± SD) were used for quantitative variables. Group comparisons were performed using independent t-tests and ANOVA as appropriate. A p-value <0.05 was considered statistically significant.

RESULTS

In the internal capsule, the mean width on the left and right side; we found the anterior limb to be 4.09 and 4.21, genu to be 6.15 and 6.30, posterior limb to be 6.40 and 6.66, genu angle to be 117.90 and 118.97, ADC-DWI to be 0.76 and 0.70 respectively. We found statistically significant difference between the left and right side across anterior limb, posterior limb, genu and ADC-DWI, except genu angle.

On the left side of internal capsule across males and females, we found the anterior limb to be 4.14 and 4.03, genu to be 6.23 and 6.06, posterior limb to be 6.68 and 6.03, genu angle to be 119.76 and 115.47, ADC-DWI to be 0.78 and 0.73 respectively. We found statistically significant difference between the male and females on the left side across posterior limb, genu, genu angle and ADC-DWI, except anterior limb.

On the right side of internal capsule across males and females, we found the anterior limb to be 4.30 and 4.09, genu to be 6.32 and 6.29, posterior limb to be 6.91 and 6.33, genu angle to be 118.14 and 120.06, ADC-DWI to be 0.72 and 0.67 respectively. We found statistically significant difference between the male and females on the right side across anterior limb, posterior limb and ADC-DWI, except genu and genu angle.

On the left side of internal capsule across 30-45, 46-60 and >60 years, we found the anterior limb to be 4.07, 4.11 and 4.13, genu to be 6.09, 6.21 and 6.48, posterior limb to be 6.66, 6.04 and 6.47, genu angle to be 117.85, 118.09 and 117.0, ADC-DWI to be 0.73, 0.80 and 0.79 respectively. We found statistically significant difference across different age groups on the left side across genu, posterior limb and ADC-DWI, except anterior limb and genu angle.

On the right side of internal capsule across 30-45, 46-60 and >60 years, we found the anterior limb to be 4.22, 4.23 and 3.88, genu to be 6.48, 6.09 and 6.12, posterior limb to be 6.62, 6.70 and 6.75, genu angle to be 117.17, 121.59 and 117.9, ADC-DWI to be 0.69, 0.71 and 0.72 respectively. We did not find statistically significant difference across different age groups on the left side across genu, posterior limb and ADC-DWI, except anterior limb and genu angle.

Table 1: Internal Capsule Measurements & Diffusion Characteristics On Either Side

	LEFT	RIGHT	P
ANTERIOR LIMB(mm)	4.09 ± 0.38	4.21 ± 0.65	0.04
GENU(mm)	6.15 ± 0.43	6.30 ± 0.83	0.039
POSTERIOR LIMB(mm)	6.40 ± 1.08	6.66 ± 1.20	0.0412
GENU ANGLE(x/180)	117.90 ± 6.07	118.97 ± 11.18	0.1792
ADC av (x 10^{-3} mm^2/s)	0.759 ± 0.063	0.70 ± 0.055	<0.0001

Table 2: Internal Capsule Measurements & Diffusion Characteristics in Either Gender On Left Side

LEFT	MALES	FEMALES	P
ANTERIOR LIMB (mm)	4.14 ± 0.25	4.03 ± 0.49	0.056
GENU (mm)	6.23 ± 0.46	6.06 ± 0.35	0.0165
POSTERIOR LIMB(mm)	6.68 ± 1.14	6.034 ± 0.86	0.000491
GENU ANGLE (x/180)	119.76 ± 4.82	115.47 ± 6.67	0.000041
ADC av (x 10^{-3} mm^2/s)	0.78 ± 0.06	0.73 ± 0.06	0.000027

Table 3: Internal Capsule Measurements & Diffusion Characteristics in Either Gender On Right Side

RIGHT	MALES	FEMALES	P
ANTERIOR LIMB(mm)	4.30 ± 0.533	4.09 ± 0.76	0.04147
GENU(mm)	6.32 ± 0.89	6.29 ± 0.75	0.4271
POSTERIOR LIMB(mm)	6.91 ± 1.11	6.33 ± 1.24	0.00367
GENU ANGLE(x/180)	118.14 ± 13.98	120.06 ± 5.71	0.1770

ADC av (x 10^{-3} mm^2/s)	0.72 ± 0.03	0.67 ± 0.06	>0.00001

Table 4: Internal Capsule Measurements & Diffusion Characteristics Across Different Age Groups On Left Side

LEFT	30-45	46-60	>60	P
ANTERIOR LIMB(mm)	4.07 ± 0.436	4.11 ± 0.30	4.13 ± 0.30	.8281
GENU(mm)	6.09 ± 0.44	6.21 ± 0.40	6.48 ± 0.35	0.0498
POSTERIOR LIMB(mm)	6.66 ± 1.20	6.04 ± 0.717	6.47 ± 1.45	0.00863
GENU ANGLE(x/180)	117.85 ± 6.87	118.09 ± 4.68	117.0 ± 7.54	0.09129
ADC av (x 10^{-3} mm^2/s)	0.73 ± 0.06	0.80 ± 0.043	0.79 ± 0.07	<0.00001

Table 5: Internal Capsule Measurements & Characteristics Across Different Age Groups On Right Side

RIGHT	30-45	46-60	>60	P
ANTERIOR LIMB(mm)	4.22 ± 0.678	4.23 ± 0.614	3.88 ± 0.56	0.4475
GENU(mm)	6.48 ± 0.80	6.089 ± 0.85	6.12 ± 0.58	0.035
POSTERIOR LIMB(mm)	6.62 ± 1.29	6.70 ± 1.02	6.75 1.59	0.9255
GENU ANGLE(x/180)	117.17 ± 14.36	121.59 ± 4.35	117.9 2.35	0.1104
ADC av (x 10^{-3} mm^2/s)	0.69 ± 0.06	0.71 ±0.03	0.72 ± 0.06	0.0689

DISCUSSION

Internal capsule is divided into anterior limb, genu, posterior limb, retrolentiform limb (retrolenticular part) and sublentiform limb (sublenticular part).[1]

The measurements of the internal capsule change depending on gender, age, and ethnicity; pathological alterations are evident with specific disorders; irrespective of it being degenerative/demyelinating diseases, Vitamin deficiency, infarction, hemorrhage, arteriovenous malformation, vascular pathologies, neoplastic conditions, parasitic diseases as well as psychiatric diseases).[1,8] Learning the standard morphometry of this region may assist clinicians diagnose & follow-up on illnesses.[1]

Magnetic Resonance Imaging (MRI) has transformed the science of neuroimaging by providing unmatched insights into the anatomical as well as functional characteristics of the human brain.[4]

The absence of substantial research across varied communities globally results in a scarcity of data on certain ethnic or regional groupings. In addition, distinct genetic, environmental, and social factors may influence brain structure and development.[4]

As a result, the present research intends to close this knowledge gap by describing the internal capsule's normative range as well as variability, as well as comprehending brain morphology throughout different regions influenced by environmental as well as genetic factors. Such data not only adds the normal reference range of values but it additionally provides insight into increasing diagnostic accuracy as well as therapeutic strategies for prevalent neurological and psychiatric illnesses.

ANTERIOR LIMB

The anterior limb connects the head of the caudate nucleus to the lentiform nucleus.[1,9] The anterior limb of the internal capsule houses thalamic as well as brain stem fibers via prefrontal cortical regions that are involved in numerous facets of emotion, motivation, cognitive processing, as well as decision making.[1,10]

In our study, we found the mean anterior limb width on the left and right side to be 4.09 and 4.21. On the left side of internal capsule across males and females, we found the anterior limb to be 4.14 and 4.03, whereas in the age groups of 30-45, 46-60 and >60 years, we found the anterior limb to be 4.07, 4.11 and 4.13. On the right side of internal capsule across males and females, we found the anterior limb to be 4.30 and 4.09, whereas in the age groups of 30-45, 46-60 and >60 years, we found the anterior limb to be 4.22, 4.23 and 3.88.

In a study carried out by Turamanlar O et al,[1] the mean widths of the anterior limb were 3.05 mm on the left side and 3.12 mm on the right side, which were in agreement with the results of our study. The width of the anterior limb of the internal capsule was found to be less in their study, compared to our study which can be attributed to the different geographic region, where the study was conducted, like this study being conducted in Turkey, while our study was conducted in India.

A decrease in anterior limb volume is associated with psychiatric disorders such as major depressive disorder, bipolar disorder, obsessive-compulsive disorder and schizophrenia.[10]

Further, in our study, we observed that the width of the anterior limb was slightly more on the right side than in comparison to that of the left side, which was similar to that observed in case of the posterior limb. A further assessment of the side in terms of gender revealed the width to be higher in males than in females on both the left and the right side.

A distributive assessment of the anterior limb across different age groups, showed increase in the width of the anterior limb with increasing age on both the sides; however we found a slight decrease in in the right anterior limb at higher age group.

Such findings were also observed with respect to posterior limb width in terms of the side, gender as well as across different age groups in our study.

POSTERIOR LIMB

The posterior limb connects the thalamus along with its lentiform nucleus.[1,9] The posterior limb of the internal capsule houses the posterior thalamic

radiations, corticospinal tract, corticorubral tract, as well as corticopontine tract.[1,2]

Herein, we recorded the mean posterior limb width on the left and right side to be 6.40 and 6.66. On the left side across males and females, it was found to be 6.68 and 6.03; with it being 6.66, 6.04 and 6.47 across the age groups of 30-45, 46-60 and >60 years. On the right side of internal capsule across males and females, was found to be 6.91 and 6.33, whereas in the age groups of 30-45, 46-60 and >60 years, it was found to be 6.62, 6.70 and 6.75.

However, Turamanlar O et al,[1] reported opposing results in their study, wherein the mean posterior width on the left side was more than that observed on the right side; with the mean left posterior width being 4.23 mm and 4.04 mm on the right side.

We observed that the width of the posterior limb was slightly more on the right side than in comparison to that of the left side, which was similar to that observed in case of the anterior limb.

GENU

Genu is structurally observed to be foremost anterior alongside the one which connects the medial as well as the lateral frontal lobes; with the most posterior aspect is the splenium in the case of corpus callosum, apart from the body being the longest, alongside the isthmus being narrow & between the splenium as well as the posterior aspect of the body.[8,11]

The corticobulbar tract fibers are situated in the genu region of the internal capsule & extend via the lower part of the primary motor area to the motor nuclei of the cranial nerves having superior thalamic radiations.[1,3]

On further assessment, we found the mean genu width on the left and right side genu was found to be 6.15 and 6.30, which was similar to the anterior and posterior limb width. On the left side across males and females, genu was found to be 6.23 and 6.06; with it being segregated as 6.09, 6.21 and 6.48 across the age groups of 30-45, 46-60 and >60 years. On the right side of internal capsule across males and females, genu was found to be 6.32 and 6.29; and in the age groups of 30-45, 46-60 and >60 years, genu was found to be 6.48, 6.09 and 6.12

The mean genu width on the right side was higher than that observed on the left side. A more distributive analysis revealed it to be higher in males on either side, with an escalation seen in level with ageing. However, we found an inverse change in the width of the genu; wherein across different ages, we observed genu to increase on the right side whereas it decreased on the left side with ageing.

A 2023 study by Reddy et al., reported the genu of corpus callosum in cases and controls to be 9.8 mm and 10.27 mm respectively.[8]

As per Turmanlar O et al., 2020 study, they reported the mean left and right genu was 6.0 and 6.05.[1] On the left side across males and females, mean genu was 5.88 and 6.06; whereas on the right side, it was 5.91 and 6.11 across males and females.

For further assessment, we followed the guidelines of one of the well-known national anatomy textbook, which was also followed by Turamanlar O et al., wherein the genu angle was expressed as 90°.[16]

The mean genu angle on the left and right side was found to be 117.90 and 118.97. The genu angle on the left side, in males and females it was found to be 119.76 and 115.47; whereas in the age groups of 30-45, 46-60 and >60 years, genu angle to be 117.85, 118.09 and 117.0. On the right side of internal capsule across males and females, genu angle to be 118.14 and 120.06; whereas in the age groups of 30-45, 46-60 and >60 years, genu angle to be 117.17, 121.59 and 117.9.

Turamanlar O et al., observed the mean widths genu was 6 mm on the left side and 6.05 mm on the right side, respectively.[1]

We observed a wider genu angle on the right side. Further, on the left side we found a wider genu angle in males, whereas it was higher in females on the right side. We also noted an increase in the mean genu angles in patients aged 46-60 years, when compared to patients aged 30-45 years, which again decreased in patients aged >60 years.

However, there were slightly different results reported by Turamanlar O et al., in their study wherein the right and left genu angles were significantly wider in females than males ($p<0.05$).[1] The mean genu angle was measured as 120.58° on the left side and 120.53° on the right side in males, while it was 123.01° on the left side and 123.43° on the right side in females

DWI -ADC

Diffusion-weighted (DW) MR imaging reveals ischemic regions in the brain within minutes after the induction of focal ischemia in experimental stroke and as soon as a patient with acute stroke is available for imaging studies.[12-15]

DW imaging is based on the random translational movement of water molecules in biologic media. The net diffusion of the molecules is referred to as the apparent diffusion coefficient (ADC).[12,16]

Because the cellular structures are distributed anisotropically, the measurement of diffusion is direction dependent; this fact emphasizes the need for measuring diffusion in several directions.[12,17]

ADC values alone are not site specific.

The mean ADC-DWI on the left and right side was found to be 0.76 and 0.70 respectively. On the left side of internal capsule across males and females, ADC-DWI to be 0.78 and 0.73 respectively; whereas across 30-45, 46-60 and >60 years, ADC-DWI to be 0.73, 0.80 and 0.79 respectively. On the right side of internal capsule across males and females, ADC-DWI to be 0.72 and 0.67 respectively, whereas across 30-45, 46-60 and >60 years, ADC-DWI to be 0.69, 0.71 and 0.72 respectively.

In the study by Helenius J et al., they reported ADC in the left side in men and women to be 0.51 & 0.52

respectively; which was also similar on the right side.[12]

We analyzed all required criteria in accordance with the requirements of our study; nevertheless, we had several limitations such as a small sample size, a single-center based research, a non-randomized sample, along with no multiple observers to evaluate the technique. To address our study's limitations, we advocate an extensive sample, multi-centric, randomized, multi-observer standardized investigation in the future.

CONCLUSION

In our study, we found statistical difference between left and right sides, across male and female gender and across various age groups in patients aged between 30-75 years, except for a few characteristics of the internal capsule. As there is limited literature available with regard to the characteristics of the internal capsule, therefore we advocate more extensive research studies to shed light on the available data, while providing supportive data to the existing literature.

REFERENCES

1. Turamanlar O, Bilir A, Horata E, Ertekin T, Özer Gökaslan Ç, Emeksiz H: Morphometry of the internal capsule on MR images in adult healthy individuals. Anat 2020, 14(1):49–52.10.2399/ana.20.028
2. Emos MC, Agarwal S. Neuroanatomy, internal capsule. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2019. Available from: https://www.ncbi.nlm.nih.gov/books/NBK542181/
3. Chowdhury F, Haque M, Sarkar M, Ara S, Islam M: White fiber dissection of brain; the internal capsule: a cadaveric study. Turk Neurosurg. 2010, 20:314–22. 10.5137/1019-5149.JTN.3052-10.2
4. Majeed I, Khan NA, Bhat GM, Wali A: MRI-based morphometric analysis of corpus callosum dimensions in adults: Impact of age and gender in Kashmir. Panacea J Med Sci. 2024, 14(3):610-6. 10.18231/j.pjms.2024.109
5. Bansal R, Gerber AJ, Peterson BS: Brain Morphometry Using Anatomical Magnetic Resonance Imaging. J Am Acad Child Adolesc Psychiatry. 2008, 47(6):619–21. 10.1097/CHI.0b013e31816c54ed
6. Sidhanth Y S, Bopaiah H, Sakalecha A, et al.: Age- and Sex-Stratified Normogram Study of Corpus Callosum Dimensions in South Indian Individuals. Cureus. 2024, 16(11): e72822.10.7759/cureus.72822
7. Garel C, Cont I, Alberti C, Josserand E, Moutard ML, Ducou le Pointe H: Biometry of the corpus callosum in children: MR imaging reference data. AJNR Am J Neuroradiol. 2011, 32:1436-43. 10.3174/ajnr.A2542
8. Reddy B, Naik D, Sakalecha AK, et al.: Role of Magnetic Resonance Imaging in Morphometric Alterations of Corpus Callosum in Stroke Patients. Cureus. 2023 15(2): e35332. 10.7759/cureus.35332
9. Johns P: Clinical neuroscience: an illustrated colour text. Edinburgh: Churchill Livingstone Elsevier; 2014.
10. Safadi Z, Grisot G, Jbabdi S, et al.: SN. Functional segmentation of the anterior limb of the internal capsule: linking white matter abnormalities to specific connections. J Neurosci. 2018, 38:2106–17. 10.1523/JNEUROSCI.2335-17.2017
11. Jain A, Naik D, Sundari A, Kumar AA: Age and gender related changes in the dimensions of corpus callosum by MRI-in south Indian population. Int J Anat Radiol Surg. 2017, 6:47-51. 10.7860/IJARS/2017/27617:2293
12. Helenius J, Soinne L, Perkio J, et al.: Diffusion-Weighted MR Imaging in Normal Human Brains in Various Age Groups. AJNR Am J Neuroradiol. 2002, 23:194–9.
13. Li F, Han SS, Tatlisumak T, et al.: A new method to improve in-bore middle cerebral artery occlusion in rats: demonstration with diffusion- and perfusion-weighted imaging. Stroke. 1998, 29:1715–20. 10.1161/01.str.29.8.1715
14. Li F, Han SS, Tatlisumak T, et al.: Reversal of acute apparent diffusion coefficient abnormalities and delayed neuronal death following transient focal cerebral ischemia in rats. Ann Neurol. 1999, 46:333–42. 10.1002/1531-8249(199909)46:3<333::aid-ana9>3.0.co;2-x
15. Warach S, Gaa J, Siewert B, Wielopolski P, Edelman RR: Acute human stroke studied by whole brain echo planar diffusionweighted magnetic resonance imaging. Ann Neurol. 1995, 37:231–4. 10.1002/ana.410370214
16. Le Bihan D, Breton E, Lallemand D, Grenier P, Canabis E, Laval Jeantet M: MR imaging of intravoxel incoherent motions: application to diffusion and perfusion in neurological disorders. Radiology. 1986, 161:401–7. 10.1148/radiology.161.2.3763909
17. Sakuma H, Nomura Y, Takeda K, et al.: Adult and neonatal human brain: diffusional anisotropy and myelination with diffusionweighted MR imaging. Radiology. 1991, 180:229–33. 10.1148/radiology.180.1.2052700.