Clinical Neurology and Neurosurgery 136 (2015) 1–4

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

# Assessment of quantitative corticospinal tract diffusion changes in patients affected by subcortical gliomas using common available navigation software

Mario Giordano*, Arya Nabavi, Venelin M. Gerganov, Amir S. Javadi, Madjid Samii, Rudolf Fahlbusch, Amir Samii

*International Neuroscience Institute; Department of Neurosurgery, Rudolf Pichlmayr Str. 4, Hannover 30625, Germany*

ARTICLE INFO

*Article history:*
Received 27 January 2015
Received in revised form 12 April 2015
Accepted 7 May 2015
Available online 27 May 2015

*Keywords:*
Corticospinal tract
Diffusion tensor imaging
Quantitative assessment
Glioma
Motor deficit
Neuronavigation

ABSTRACT

*Objective:* The aim of this study is to analyze the quantitative DTI parameters of the CST in patients suffering from subcortical gliomas affecting the CST using generally available navigation software.
*Methods:* A retrospective study was conducted on 22 subjects with diagnosis of primary cerebral glioma and preoperative motor deficits. Exclusion criteria were: involvement of motor cortex, lesion involving both hemispheres, previous surgical treatment. All patients were studied using magnetic resonance imaging (MRI) with diffusion tensor imaging (DTI) sequences. Volume, fractional anisotropy (FA) and mean diffusivity value (MD) of the entire CSTs were estimated. Moreover, distance from midline, diameters, FA and MD were calculated on axial images at the point of minimal distance between tumor and CST. Statistical analysis was performed.
*Results:* There was a statistically significant difference of CST volume between affected and non-affected hemispheres ($p < 0.01$). Mean overall/local FA, overall/local MD and sagittal diameter of CST were also significantly different between the two sides ($p < 0.05$). Correlation tests resulted positive between the shift of CST and overall/local MD. Moreover there is significance between CST volume of tumor hemisphere and preoperative duration of motor deficits ($p < 0.05$).
*Conclusion:* The present study has demonstrated for the first time a significant difference of DTI based quantitative parameters of the CST between a tumor affected and a non-affected hemisphere in patients with a corresponding motor deficit. This preliminary data suggests a correlation between DTI based integrity of CST and its function.



## 1. Introduction

Recent studies have suggested that aggressive resection for low- and high-grade gliomas is associated with a better overall and progression free survival rate [1–6].

Advanced techniques such as functional magnetic resonance imaging (fMRI) and Diffusion Tensor Imaging (DTI) have been implemented to delineate the intent of resection and potentially reduce postoperative neurological deficits. Diffusion imaging is conventionally used in neurosurgery to estimate the position of important white matter fibers such as corticospinal tract (CST) [7,8], arcuate fasciculus [9], visual pathway [10,11], spinal lemniscus [12] and even cranial nerves [13,14]. On the other hand DTI quantitative parameters underlying the 3D reconstruction are rarely processed to obtain further information about the fiber bundles.

The aim of this study is to analyze the quantitative DTI parameters of the CST in patients suffering from subcortical gliomas affecting the CST using generally available navigation software.

## 2. Materials and methods

We prospectively collected data of 22 patients treated at our Institute with an initial diagnosis of primary cerebral glioma and preoperative motor deficits. Exclusion criteria were: involvement of motor cortex, lesion involving both hemispheres, previous surgical or radiotherapy treatment. Patient's population included

*Abbreviations:* CST, corticospinal tract; MRI, magnetic resonance imaging; DTI, diffusion tensor imaging; FA, fractional anisotropy; MD, mean diffusivity value; oFA, overall FA; oMD, overall mean diffusivity; CSTV, volume of CST; TV, tumor volume; lFA, local FA; lMD, local MD; sag, sagittal diameter; cor, coronal diameter; dCST, distance between midline CST.

* Corresponding author. Tel.: +49 511 27092865; fax: +49 511 27092706.
*E-mail address:* mario.giordano@alice.it (M. Giordano).

http://dx.doi.org/10.1016/j.clineuro.2015.05.004

9 female and 13 male, mean age was 54.5 years (range 30–79 years). The period between initial motor deficits and treatment was on average 8 weeks (range 1–24 weeks). All patients had standard neurological examination including grade of motor strength using Medical Research Council Scale of 0–5 [15] and underwent preoperative MRI including DTI.

### 2.1. Diagnostic imaging and processing

Anatomical images were acquired with a 3-T MRI scanner (Siemens Magnetom Allegra; Siemens Medical) using T1-weighted magnetization prepared rapid acquisition gradient echo (MPRAGE) slice thickness 1 mm, field of view 320 mm$^2$, echo time (TE) 3.5 ms, repetition time (TR) 2150 ms with and without intravenous contrast; T2-weighted thickness 1 mm, field of view 320 mm$^2$, TE: 505 ms, TR: 3200 ms. Functional data (fMRI) were also acquired with the same scanner using blood-oxygen-level dependent (BOLD) images depicting cortical regions corresponding to hand and foot on both sides and speech areas if the tumor involves the dominant hemisphere, slice thickness 3 mm, field of view 1152 mm$^2$, TE: 30 ms, TR: 1980 ms. Diffusion tensor imaging (DTI) sequences were obtained with 1.6-mm thickness; 40 slices; 12 directions; 1 baseline; no intersection gap; echo time, 86 ms; repetition time, 5600 ms; number of excitations, 1; acquisition matrix size was 128 × 128; $b$-value 1000 s/mm$^2$. The MRI data were stored in a digital imaging and communication in medicine (DICOM) file and transferred to a neuronavigation planning workstation (iPlan; Brainlab AG, Heimstetten, Germany) for image processing using version 3.0 of the software. After rigid registration of the functional and anatomical sequences the fiber tracking was performed.

For tracking the CST, two main region-of-interests (ROI) were selected: the functional area corresponding to contralateral extremities was used as first ROI and a second ROI was positioned at the level of the homolateral cerebral peduncle. Fibers coursing through both ROIs were included. A fractional anisotropy (FA) threshold of 0.15 [16] and minimum fibers length of 80 mm were selected. Obviously inaccurate fibers (e.g. crossing the midline up to the brainstem) were discarded manually drawing of a new ROI and using the “exclude” function of the software.

After the generation of both CSTs the tumor was interactively segmented obtaining three-dimensional color imaging of the 3 structures. The following parameters were then calculated using navigation software integrated tools: overall FA of the CST (oFA), overall mean diffusivity of the CST (oMD) (mm$^2$/s), volume of both CSTs (CSTV) and tumor volume (TV) (cm$^3$). Fractional anisotropy is a scalar value that ranges from 0 (fully isotropic water diffusion) and 1 (fully anisotropic). This parameter reflects fiber organization and myelination: a high FA value reflects a better integrity of the CST [17–19]. Mean diffusivity is another important value in diffusion imaging: it is a parameter of average molecular motion affected by cellular size and integrity [20–22] and has been recently used also to detect brain degeneration in multiple sclerosis [23].

The axial plane with the shortest distance between lesion and homolateral CST was then selected and used for further measurements (Fig. 1): local FA of CST (lFA), local MD of CST (lMD) (mm$^2$/s), sagittal (sag) and coronal (cor) diameter (mm) of both CST. Moreover the distance between midline and each CST (dCST) was measured on the same axial plane as above and the difference between these two values was considered as CST shift of the pathological hemisphere.

### 2.2. Statistical analysis

Commercially available software (IBM SPSS Statistics for Mac, Version 22.0. Armonk, NY: IBM Corp.) was used for data analysis. In addition to descriptive statistic and paired $t$-test, Pearson's,

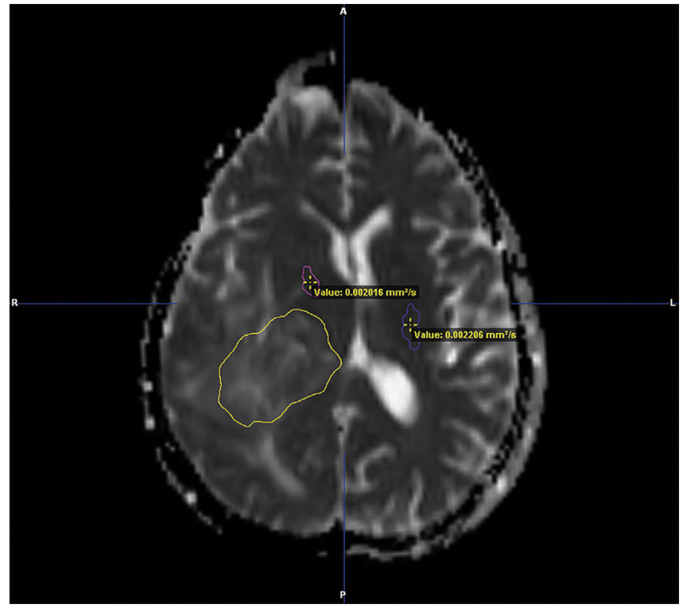


**Fig. 1.** Magnetic resonance imaging of a patient affected by right parietal glioblastoma. Axial apparent diffusion coefficients images corresponding to the plane with the shortest distance between lesion and homolateral CST showing local mean diffusivity value. Tumor segmentation (in yellow). Corticospinal tract on tumor side (violet). Corticospinal tract on the control side (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Kendall's tau and Spearman's correlation tests were used. Significance was ascribed in case of error probability of $p < 0.05$.

## 3. Results

The results are reported in Table 1. Mean tumor volume was 37.47 cm$^3$ (SD, 27.28 cm$^3$).

Corticospinal tract volume (CSTV): Tumor side 8.07 cm$^3$ (SD, 3.77 cm$^3$), control side 11.03 cm$^3$ (SD, 3.89 cm$^3$).

There was a statistically significant difference in CSTV between affected and non-affected hemispheres ($p < 0.01$).

Overall FA (oFA): Tumor side 0.4045, control side 0.4331.

**Table 1**
Results of the studied values on the affected and contralateral (.Con) hemisphere. CSTV: corticospinal tract volume; oFA: overall fractional anisotropy; oMD: overall mean diffusivity; lFA: local fractional anisotropy; lMD: local mean diffusivity; Sag: sagittal diameter of the corticospinal tract; Cor: coronal diameter of the corticospinal tract; Mid Dist: midline distance of corticospinal tract in the axial plane with minimal distance to the tumor.

| | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| CSTV | 1.072 | 16.663 | 8.06795 | 3.766355 |
| CSTV.Con | 3.883 | 19.855 | 11.02677 | 3.888230 |
| Tumor volume | 6.759 | 99.720 | 37.46577 | 27.096644 |
| oFA | 0.3412 | 0.4740 | 0.404495 | 0.0383197 |
| oFA.Con | 0.3427 | 0.4924 | 0.433109 | 0.0306526 |
| oMD | 0.002258 | 0.003380 | 0.00265909 | 0.000254067 |
| oMD.Con | 0.002259 | 0.002865 | 0.00245886 | 0.000143637 |
| lFA | 0.2039 | 0.8588 | 0.468986 | 0.1691367 |
| lFA.Con | 0.2667 | 0.7768 | 0.575636 | 0.1505878 |
| lMD | 0.001788 | 0.004755 | 0.00263345 | 0.000741257 |
| lMD.Con | 0.002054 | 0.002473 | 0.00226914 | 0.000133712 |
| Sag | 2.5 | 19.3 | 11.809 | 4.1527 |
| Sag.Con | 4.8 | 28.3 | 15.409 | 5.7821 |
| Cor | 1.9 | 12.9 | 5.877 | 2.8413 |
| Cor.Con | 3.2 | 12.5 | 6.382 | 2.3637 |
| Mid Dist | 0.0 | 26.8 | 16.368 | 9.7779 |
| Mid Dist.Con | 10.5 | 32.4 | 20.545 | 5.3146 |