Advanced MRI analysis methods for detection of focal cortical dysplasia

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ABSTRACT − In many patients, lesions of focal cortical dysplasia (FCD) may go unrecognized by standard radiological analysis. This is due to the fact that identification of many of these malformations on visual inspection of conventional MRI is difficult due to their subtlety and the complexity of the brain’s convolutions. Quantitative MR image processing methods have the potential to help identify lesions that may be overlooked by conventional radiological evaluation. To increase the sensitivity of MRI for the detection of subtle lesions of FCD, we recently developed voxel-based image post-processing methods, including first-order texture analysis and morphological processing modeled on known MRI features of FCD. Using these methods we were able to increase the sensitivity over conventional MRI analysis by more than 30%, while maintaining a high degree of reliability. The image processing methods we developed improve visual detection of FCD, even in cases where no lesion is obvious on MRI. Therefore, these techniques could allow a more precise evaluation of patients with partial epilepsy who could benefit from surgery.

KEY WORDS: focal cortical dysplasia, epilepsy, magnetic resonance imaging, image processing, texture analysis

Relevance of MRI in epilepsy surgery

The multidisciplinary approach to pre-surgical evaluation is based on clinical phenomena, EEG data, neuropsychological assessment and neuroimaging. The advent of magnetic resonance imaging (MRI) has had a major impact on the pre-surgical evaluation of patients with focal epilepsy by allowing the identification of a lesion in many patients previously considered to have cryptogenic epilepsy. Surgical removal of lesions identified by MRI that are considered to be part of the epileptogenic zone improves surgical outcome in patients [1,2]. Malformations of cortical development are increasingly recognized as an important cause of intractable focal epilepsy. Compared to other brain lesions that cause epilepsy, these malformations tend to affect younger patients.

Taylor-type focal cortical dysplasia (FCD) [3] corresponds to a localized disruption of the normal cortical lamina associated with an excess of large, aberrant neurons, an increase in cortical thickness, and often, abnormal neuroglial elements in the underlying white matter (WM). On MRI, FCD is mainly characterized by vari-
able degrees of cortical thickening, a poorly defined transi-
tion between gray matter (GM) and WM, and hyperin-
tense signal within the dysplastic lesion with respect to
normal cortex [4]. FCD lesions are mostly located in
temporary areas.

MRI of the brain has made it possible to detect FCD in an
increasing number of patients [5,6]. However, the number of
cases treated surgically remains small and the prognosis
sometimes poorer than in patients undergoing surgery for
other types of lesions. This is partly due to the fact that
identification of many FCD lesions on visual inspection of
conventional MRI is difficult due to their subtlety and the
complexity of the brain’s convolutions. In patients with no
detectable structural lesion, so-called “MRI-negative” or
cryptogenic cases, intensive EEG monitoring with intrac-
trally implanted electrodes is usually performed.

The potential of image processing in the detection of focal cortical dysplasia

Curvilinear reformatting of three-dimensional MRI [7] is a
qualitative image analysis that attempts to improve lesion
visualization by providing a more realistic anatomical
display of the gyral structure of the hemispheric convexi-
ties. Compared to the standard orthogonal MRI evaluation,
this approach also reduces the asymmetric sampling of
GM and WM that may lead to false-positive results.
However, the inherent complexity of the brain’s convolutional
pattern makes the visual identification of FCD les-
sions difficult. Consequently, the shortcoming of conven-
tional MRI methodologies and curvilinear reformatting is
that assessment is entirely subjective, and has to take the
normal variations in gyral morphology into account.
Novel quantitative MR images processing methods have
the potential to help identify lesions that may be over-
looked by conventional radiological evaluation of films.

To date, only a few imaging studies based on a limited
number of patients have addressed the question of struc-
tural abnormalities associated with malformations of cor-
tical development. In a volumetric study of 18 patients
with heterotopias, volume reduction of extra-lesional
hemispheric GM was found in 15 patients and in the
contralateral hemisphere in 9/10 patients in whom there
were apparently unilateral abnormalities [8]. Voxel-based
morphometry in ten patients with different types of mal-
formations of cortical development, mainly heterotopia,
showed increases in GM density in the lesional areas [9].
Beside morphology, texture is an important feature for
visual assessment of an image. The texture of an image can
be described by the distribution of brightness and darkness
within that image. Texture analysis is the term used for
methods developed to quantify image texture. Computer-
based texture analysis of digital images provides quantita-
tive information about spatial gray level variations in pixel
neighborhoods [10], and is more sensitive to image tex-
tural changes than the human eye. In medical imaging,
texture analysis has been shown to increase the level of
diagnostic information extracted from many modalities
such as MRI and ultrasound, and facilitates characteriza-
tion of differences in appearances unrecognizable by vi-
sual observation. Reported applications include classifica-
tion of pathological tissue in liver, thyroid, breast, kidney,
prostate and the heart, and characterization of brain tu-
mors and human trabecular bone [11-13]. Texture analysis
has also been used to identify pathology in Alzheimer’s
disease [14], temporal lobe epilepsy [15] and multiple
sclerosis [16].

Texture analysis and morphological
processing allow increased detection
of focal cortical dysplasia

To improve our ability to detect dysplastic lesions in
patients with intractable partial epilepsy, we recently de-
developed voxel-based image processing techniques, in-
cluding pixel intensities, with regard to GM and WM,
local gradient and GM thickness. These features were
chosen to model, in vivo, the pathological characteristics
of FCD. We hypothesized that such image post-processing
could increase the sensitivity of MRI for the detection of
subtle lesions of FCD [17].

We selected 16 patients who had histologically proven
FCD at surgery. All patients had focal corticectomies. In
eight patients, FCD had been recognized on MRI, prior to
surgery. In the remaining eight patients, the MRI had been
reported as normal. In patients in whom no lesion was
visible on MRI, surgery was based on strong clinical and
EEG co-localizing data. Resections were carried out in-
volving the parietal lobe in seven patients and the frontal
lobe in nine patients. Fourteen patients became seizure-
free and two had a significant reduction in frequency and
severity of the attacks (mean follow-up 26 months). Pre-
operative images were acquired on a 1.5 T scanner (Gy-
roscan, Philips Medical System, Best, The Netherlands)
using a T1-fast field echo sequence. Image processing
features were calculated for each individual voxel within
the T1-weighted 3D MRI, resulting in a three-dimensional
map for each feature. Details about modeling of the differ-
ten characteristics of FCD have been published elsewhere
[17]. In brief, to model cortical thickening, we calculated,
for each voxel, the number of consecutive GM voxels in
each possible direction. To model the blurring of the
GM-WM transition, we calculated the absolute gradient
of gray level intensities, a first-order texture feature. To model
the hyperintense signal within the focal cortical dysplasia
on T1-weighted images, we developed a feature that cal-
culated the absolute difference between the intensity of a
given voxel and the intensity at the boundary between GM
and WM, defined using a histogram. To maximize visibil-
ity of FCD lesions, a ratio map (GM thickness x relative
intensity/gray level intensity gradient) was generated.
MR images and ratio maps for the 16 patients and 20 healthy control subjects were presented, in random order, to two trained observers who were unaware of the final diagnosis. Sensitivity (predicted positives/total positives) was 87.5% (14/16) for the ratio maps, compared to 50% (8/16) for MRI (\(P < 0.003\)). Specificity (predicted negatives/total negatives) was 95% (19/20) for ratio maps and 100% (20/20) for MRIs.

The figure shows an example of a patient with an obvious FCD lesion on preoperative MRI, and one example of a patient in whom the MRI was reported as normal, but for whom ratio maps showed a lesion.

**Conclusion**

Detection of subtle dysplastic lesions may be improved by performing computerized quantitative analysis of the structural changes that characterize FCD pathologically and in vivo on MRI. This approach makes use of the large amount of data available in volumetric MRI scans, much of which may be too subtle to be appreciated by visual analysis alone. It is our hope that these new techniques, ultimately, will become more widely available and permit identification of FCD in many more patients with intractable epilepsy undergoing evaluation in specialized centers.

![Figure 1](image-url)
Acknowledgements

This work was supported by a grant of the Canadian Institutes of Health Research (CIHR #100203) and the Savoy Foundation for Epilepsy.

References

1. Fish DR, Smith SJ, Quesney LF, Andermann F, Rasmussen T. Surgical treatment of children with medically intractable frontal or temporal lobe epilepsy: results and highlights of 40 years' experience. Epilepsia 1993; 34: 244-7.