SIDE DIFFERENCES IN MRI-SCANS IN FACIAL PALSY: 3-D MODELING, SEGMENTATION AND GRAY VALUE ANALYSIS

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ABSTRACT

In this paper, we describe a method to analyze facial muscles and display structural changes occurring under normal and pathological conditions from segmented MR images. Orbicularis oculi and zygomaticus muscles are isolated from the surrounding tissues and their gray values analyzed.

We use 3 Tesla magnetic resonance imaging (MRI) and special image processing tools to produce high quality images and 3-D models of human heads from patients suffering from peripheral facial palsy as well as from healthy probands.

Although peripheral facial palsy is the most common pathology of the cranial nerves with an incidence ranging from 20 to 30 cases per 100,000 people, only a minority of the patients need a far-reaching surgical treatment. A profound diagnostic is essential before deciding for a drastic reconstructive surgery of the face due to the large variety of surgical techniques. This does not only include the classification of the etiology but also of the degree and distributions of the damage of the nerve and of the effected muscles are essential.

Thus, we propose a method to segment and analyze facial muscles from MR data, and to distinguish palsy and normal facial side by measuring local gray values and calculating gradient distributions.

Keywords: MRI, Segmentation, 3-D Modeling, Numerical methods, facial palsy.

1. INTRODUCTION

The term facial palsy summarizes incomplete loss (paresis) as well as the complete loss (paralysis) of facial nerve function. The distinction is highly important, as the indication for surgical reconstruction in patients with incomplete facial palsy has to be assessed much more critically. On the other hand, the reconstruction in case of a complete functional deficit is more complex. Permanent facial palsy and no transient functional deficits are the main indication for surgical reconstruction of facial nerve function.

Depending on the localisation of the lesion site, peripheral facial nerve lesion is separated from central facial nerve lesion: in peripheral palsy, the facial nerve fibres or the motoneurons in the brainstem nucleus are damaged. In contrast, the lesion site in central palsy is located central to the nucleus (supranuclear lesion) in the course of the corticonuclear tract. The otolaryngologist or head and neck surgeon is mostly confronted with patients with peripheral nerve lesion. However, sometimes the exact localisation of the lesion might be unclear, for instance in patients after brainstem astrocytoma surgery.

The type of palsy must be clarified before a reconstructive surgery because any kind of direct facial nerve reconstruction is not effective in patients with central palsy.

From the functional point of view, two different situations have to be distinguished: Firstly, patients without any sign of facial nerve regeneration due to complete interruption of re-sprouting of axons proximal to the lesion site are candidates. Second, patients who have developed spontaneous axonal sprouting but have a functionally hindering defective healing not compensated by central brain plasticity are also candidates for surgical rehabilitation. Defective healing without spontaneous regeneration is impossible. The most important clinical signs of facial nerve defective healing are: a) dyskinesia, i.e. abnormal mimic movements during voluntary action, b) synkinesia, i.e. involuntary synchronous mimic movements while the patient is performing another voluntary movement, and c) autoparalytic syndrome as a special form of synkinesia characterized by synkinetic activity of antagonistic muscles. The synchronous antagonistic movements are detectable using electromyography but the clinical result is a decreased or not visible muscle activity of the intended mimic movement. Dyskinesia and synkinesia can lead to d) hyperkinesia, i.e. an abnormal much stronger movement than physiologically used.

An exact classification of the individual facial palsy due to the above mentioned criteria is mandatory prior to surgical decision making. In addition, the mimic musculature itself, the cerebral cortex and the other cranial nerves have to be examined for pathologies. There have been attempts to identify these nerve changes in MRI; Sartoretti-Schefer S (1998) studied correlation between T2 weighted three dimensional fast spin echo MRI and intraoperative findings for facial nerves in peripheral facial nerve palsy. Correlations between the swelling of the facial nerve and visualization of an enhanced segment by MRI have been studied by In Sup Kim (2007) and Burmeister (2011).

Facial muscles have also been identified and measured in previous studies. MRI measurements of individual muscles and with the mean muscle dimensions was made to assess muscle wasting in facial and tongue muscles in patients with myasthenia gravis (Farrugia 2006). Moreover orbital magnetic resonance imaging (MRI) was used to investigate the structural basis of motility abnormalities in congenital fibrosis of the extraocular muscles (Joseph 2010).

The aim of our study is to gain more appropriable information about the mimic muscles innervated by the facial nerve before, but also after the surgery during recovery. By this, not only the decision for a reconstructive procedure can be supported, but also the postoperative benefit of the procedure can be quantified.

For this purpose, 3-D modelling and segmentation techniques are employed to isolate specific regions of interest from MR data and special computational tools are developed to qualify and quantify facial muscle morphology.

2. MATERIAL AND METHODS

Specific gray value information, 3-D modeling and segmentation techniques have been applied to monitor quadriceps femoris in paraplegic patients undergoing electrical stimulation as described in (Helgason 2005) and (Gargiulo 2010). Similar techniques are being used here.

In this work we develop high (0.67 to 1.0 mm) resolution human head models from segmented MR images. These models have detailed 3-D representation of major tissue surfaces. The gray values distribution within the segmentation masks may offer indications on the muscle conditions and account the differences between denervated and innervated side. For this purpose, we measure mean gray values from the segmented muscles (particularly zygomaticus major and minor and orbicularis oculi muscles), its changes along the scanning axes (z-axis) and finally the gradient distribution.

2.1. MR data

We analyse 17 subjects with unilateral palsy. MRI images were acquired on a 3 Tesla MRI between years 2006 and 2010 (Magnetom Tim Trio, Siemens, Erlangen, Germany) of the head and the face in the department of radiology I in Jena, Germany (Volk 2010). The entire MR imaging was performed using a dedicated 12-channel head coil provided by the manufacturer. All patients were examined in supine position. The imaging protocol of all patients included a sagittal T1-weighted sequence (TR 2300ms, TE 3.03ms, flip angle 9°,voxel size 1mm × 1mm × 1mm [=1mm^3], matrix 256 x 256, TA 5:21 min) covering the whole head including the face. Each slice has 256 × 256 pixels, and each pixel has a gray value within the 4096 gray-scale values, meaning that it is represented with a 12-bit value. The contiguous slice thickness was 1.0 mm and pixel resolution was 1.0 mm. A total data set from a single scan of 192 slices is therefore (256 × 256 × 12 × 192)/8 = 1,9 * 10^7 bytes, considering that 2 bytes are needed for 12 bit representation then a data set of this type is approximately 36 MB. This data set gives a complete 3D description of the tissue within the head.

During our study we developed an improved coronal T1-weighted fast low angle shot 3D-sequence with high spatial resolution (TR 5.67ms, TE 2.48ms, flip angle 11°,voxel size 0.67 mm × 0.67 mm × 0.67 mm [=0.3mm^3], matrix 384 x 384, TA 9:35 min), focused on the facial muscles only including the face and the forehead. Slice orientation was tilted by 90° compared to the orthogonal plane running parallel to the hard palate. In this case, a typical data set with 192 slices will be approximately 81 MB. From 2010 on, we used both sequences to get an optimum of information about the facial muscles.

Figure 1 shows a sagittal view from the two MR protocols used in this work. The difference between figure 1A (protocol 1) and B (protocol 2) is clear; the image resolution and contrast are much better in the latest protocol (figure 1B), this improvement facilitates the segmentation work.

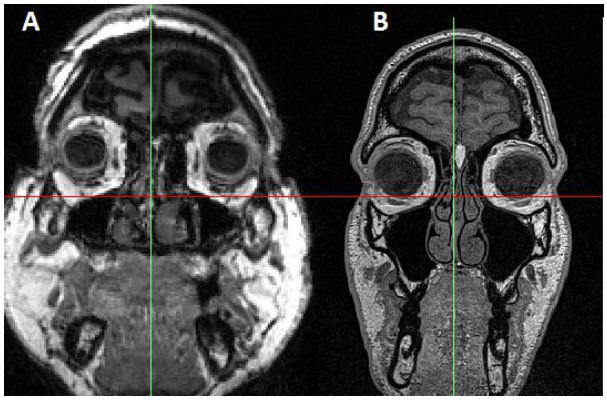

Figure 1: Comparison between sagittal views from two different MR sequences: protocol 1, T1-weighted sequence (A); protocol 2, T1-weighted fast low angle shot 3D-sequence with high spatial resolution (B).

2.2. Image processing

In order to isolate the single muscle segment and measure the growth, MR data are imported into a special image processing and editing computer program called MIMICS (www.materialise.com). In this software environment, the 3-dimensional form of the

facial muscles is reconstructed and specific regions of interest (ROI) are extracted and isolated.

Segmentation process begins by establishing a threshold, which discriminates the region of interest from the rest by selecting appropriate ranges of gray values (GV). From the visual point of view thresholding allows highlighting (for example in different colors) pixels with certain gray values from the others. In an M × N slice, each element in the image matrix *a[m,n]* displays a level of brightness coded by a grey value which in medical imaging varies from 0 to 4095 (= 2^{12} − 1). For example, the region of interest to be visualized is between GVmin to GVmax then the threshold test condition will appear as in (1):

If GVmin <= a[m,n] <= GVmax then a[m,n] = object = color
Else a[m,n] = background (1)

After thresholding further segmentation tools are usually required to isolate ROI from surrounding areas. Region growing for example is a segmentation tools used to eliminate floating pixels from belonging to the selected threshold. It is often used when determining pixel class membership: pixels that belong to the same region are connected. Other operations such as Boolean and morphological are possible on defined pixel classes in order to improve the segmentation work.

MRI show higher detail in the soft tissues such as tendons and ligaments but very often MR data require more difficult and time consuming segmentation work compared to CT because of the absence of defined thresholds for specific tissues such as muscle, bone, fat, etc. (Gargiulo 2011). In this work, depending on the quality of the MRI data, automatic segmentation techniques are combined with manual editing to correct misclassified pixels.

2.3. Facial muscle segmentation

3-D representation of major muscle tissues within face including orbicularis oculi, zygomaticus major and minor, nasalis and levator labii superior muscles were developed here. We used E-anatomy templates (http://www.imaios.com/en/e-Anatomy) to localize the different facial muscles. As a control, muscles of the non-injured contralateral sides were segmented and analysed.

The facial muscle threshold for the patients scanned with the first protocol (Fig.1A) is [300, 600] GV while the muscle threshold for the patients scanned with the second protocol (Fig.1B) is [50, 300] GV. Other tissues surrounding the facial muscle are displayed within the same gray value intervals. For this reason editing tools applied slice by slice were used to isolate the muscles.

The process starts from a cross section where the selected tissue boundaries are well visible. A contour is manually drawn around the region of interest (ROI) and projected to the next cross sections in both directions. If the contour fits well the new cross sectional area is then projected unchanged forward to the next slice, otherwise it is adapted using manual editing and then projected to the next slice. The process continues until all cross sections containing the selected ROI are covered. The contour areas are then erased creating a gap between the ROI and surrounding.

Finally, the facial muscle mask is created applying a region growing procedure which separates the edited ROI which is no longer connected to the surrounding (tissue). The result of the segmentation process applied on the two protocols is shown in figure 2.

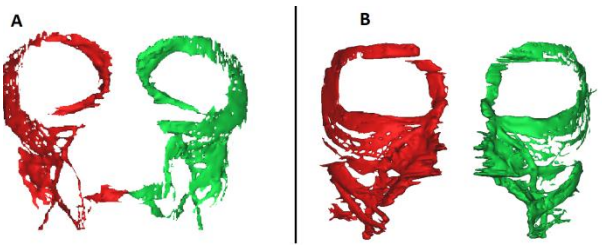

Figure 2: 3-dimensional reconstruction from facial muscle segmentation (right –red mask, left-green mask) from protocol 1 (A) and protocol 2 (B).

Immediately available after segmentation are the mask volumes and mean gray values. The distribution of mean gray values for zygomaticus and orbicularis oculi from all the patients included in the study is shown in figure 3. Red bars indicate mean gray values from palsy side while blue bars indicate the healthy contralateral side, in figure 3A are seen zygomaticus GVs and in figure 3B orbicularis oculi GVs.

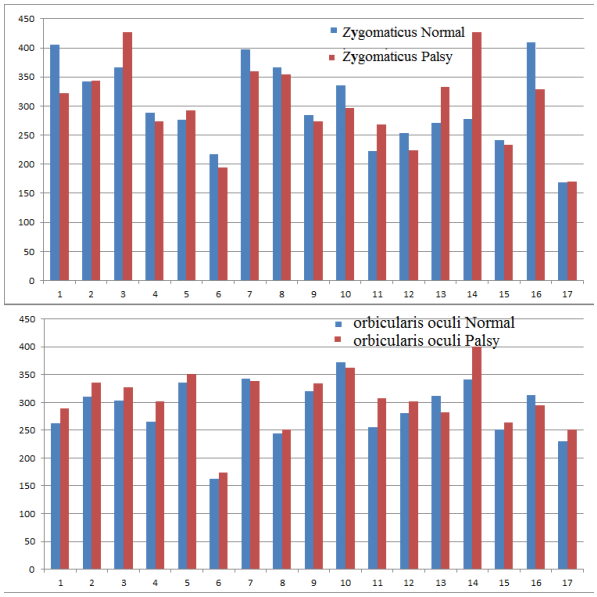

Figure 3: Mean gray values from segmented mask: Zygomaticus major and minor (A), and orbicularis oculi (B).

The segmentation mask is exported as matrix of dimension: np × 4, where np is the number of pixels contained in the mask and the four columns account respectively the voxel coordinate x, y, z and the relative GV. These data are further processed in Matlab (Matworks Inc).

2.4 Mean Gray values along the cross section

Qualitative and quantitative information concerning the segmentation mask are obtained calculating, the mean GV on each cross section along the scanning axes (z). In this way the segmentation masks representing facial muscles from palsy and normal sides can be evaluated and compared (Fig. 4). The facial muscle lengths are between 60 and 100 mm depending from patient anatomy (in our study the region of interest start above the orbicularis oculi and end above the labialis) the slice increment is 0.1 mm therefore the number of mean values is between 60 and 100. In figure 4 the right (palsy) profile is 78,95mm while the left (normal) profile is 87,95 mm long.

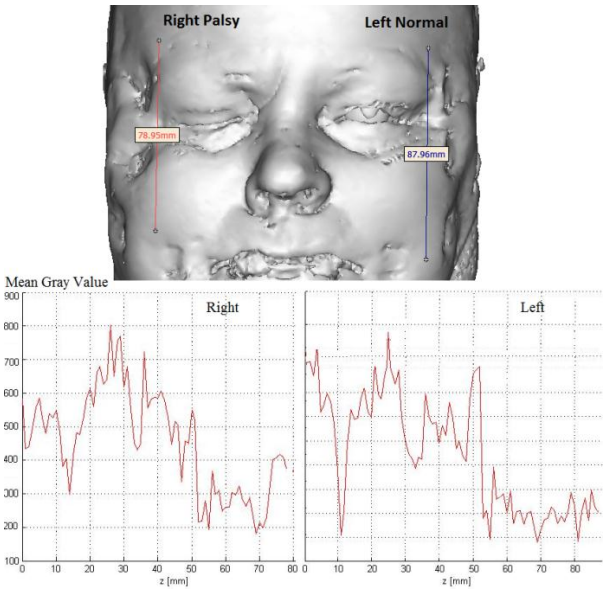

Figure 4: Patient with right palsy and associated mean GV profile along the z axes.

2.5 Gradient distribution

Consider a cross section from the MR data in which the tissue composition is given by a scalar field, GV (associated to each pixel), so at each point (*x*,*y*,*z*) the tissue is displayed with GV(*x*,*y*,*z*). At each pixel in the image, the gradient of GV at that point will show the direction the tissue GV changes most quickly. The magnitude of the gradient will determine how fast the GV rises in that direction. The algorithm to calculate and display the gradient distribution from the segmented muscle was developed in Matlab (Matworks Inc).

First, the gradients were computed using a central finite difference approximation for each voxel. So for each point f(x, y, z) each gradient component is found by (2):

$$\frac{\partial f}{\partial x} = f\left(x + \frac{h_x}{2}\right) - f\left(x - \frac{h_x}{2}\right)$$
$$\frac{\partial f}{\partial y} = f\left(y + \frac{h_y}{2}\right) - f\left(y - \frac{h_y}{2}\right) \qquad (2)$$
$$\frac{\partial f}{\partial z} = f\left(z + \frac{h_z}{2}\right) - f\left(z - \frac{h_z}{2}\right)$$

Where h_x, h_y and h_z are the separation between the adjacent points in x, y and z directions, respectively. This gradient magnitude distribution was then visualized using isosurfaces and color coding as can be seen in figure 5 (same patient of figure 4).

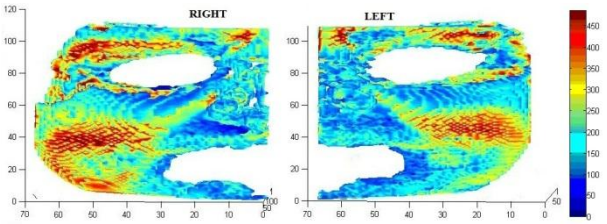

Figure 5: 3-D gradients distribution and color coding from a patient with right palsy: high gradients area is colored in red, low gradient area in blue.

3. RESULTS

Muscle volumes are calculated from the segmented data. The result from such segmentation process depends strongly upon the MR data quality. So far, our volume measurements are not reliable in term of absolute value; indeed the segmentation accuracy and the resolution of the images are not yet optimal. What we are actually using are the differences between volumes: within the same data set in order to compare healthy from palsy side and from time to time between different MR data to monitor recovery process in patient undergoing surgical treatments. In figure 6 volume changes are displayed in a patient with idiopathic facial palsy on the right side with good recovery in less than 3 month. The patient is scanned in the first week after onset of palsy (fig.6.A) and then again after 3 months (fig.6.B). Here it can be noticed that the difference between left and right muscles volume is significantly reduced in the first scan on the paretic side.

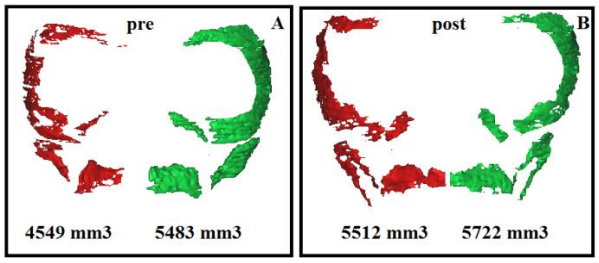

Figure 6: Muscle 3-D reconstruction and volume changes in a patient with idiopathic facial palsy on the right: 1st scan in the first week after onset of palsy (A), 2nd scan after complete recovery after 3 months (B).

The analysis of the mean gray value from the segmented mask (see figure 3) shows that orbicularis oculi GV on the palsy side tend to have higher values compared to normal: 13 from 17 patients measured. Vice versa zygomaticus muscles GV on the palsy side tend to have lower compared to normal. The measurements from the same 17 patients show that: 10 patients have lower GV value, 2 times approximately the same value, 5 patients have higher GV on palsy

side. This fact can be seen also in figure 4 where the patient gray value along the cross section show higher GV in the region of orbicularis oculi (first 30 mm of the GV profile) and generally lower in the region of zygomaticus muscles.

The analysis of the gradient shows also some interesting data. Figure 7 gather the gradient distributions from 4 patients and 2 controls. The histograms highlights that left and right gradient distributions are never completely symmetric even in control subjects. Moreover, our preliminary results show a strong tendency of having higher gradient on the palsy side meaning that there is more variability between gray values in the regions where the muscles are denervated. Likewise on the healthy side, there is noticeable higher number of pixels with low gradient meaning that in these volumes there are small differences between pixel gray values.

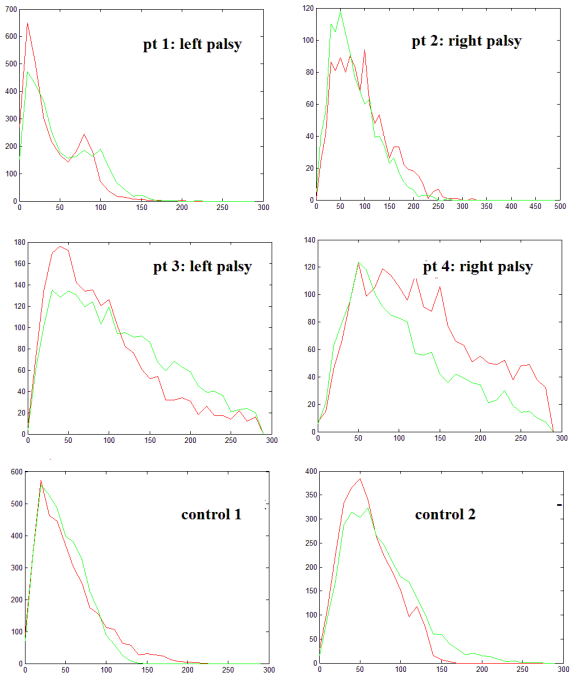

Figure 7: histograms showing gradient distributions: in red the right side and in green the left side.

Finally for the patient depicted in figure 4 (patient with idiopathic facial palsy on the right) we develop the 3-D gradient distribution to observe local changes from time to time. Figure 8 shows that in the first scan (fig.8.A) the right side (with acute idiopathic palsy) has higher gradient, above 300 GV, especially in the region of orbicular oculi muscle. The situation changes in the second scan when the patient recovers (fig.8B). Here the high gradient areas are similar on both side of the face.

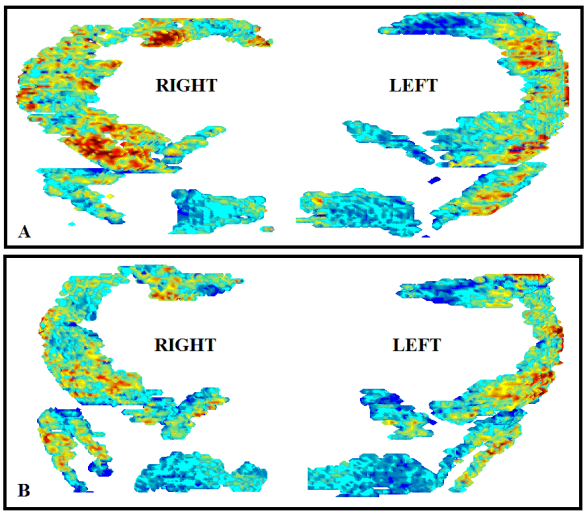

Figure 8: 3-D gradient distribution before (A) and after palsy recover (B)-on the right side.

4. CONCLUSION

The technique introduces the possibility to determine structural changes in individual facial muscles and muscle groups selectively. Comparisons between both sides and also comparisons over time are possible. Therefore, using these techniques, even before opening the skin, the surgeon has already information about the quality and quantity of the facial muscles. Considering theses information can help to choose the optimal concept in facial reconstruction for the individual patient.

During the long time of recovery after a reconstruction of the facial nerve, the technique can help to quantify the process of reinnervation. This information can not only improve individual concepts of physiotherapy but also help to understand principal concepts of de and re-innervated muscles. So we hope to develop a valuable tool for facial surgeons, physiotherapists but also for basic research.

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