```
In [124]: import numpy as np
          import os
          import matplotlib
          import matplotlib.pyplot as plt
          from matplotlib.pyplot import figure
          import nibabel as nib
          import scipy
          from scipy import optimize
          from scipy.optimize import minimize
          from scipy.stats import mode
          from sklearn.utils.extmath import weighted_mode
          from skimage import transform as tf
          from skimage.transform import warp, AffineTransform
          from sklearn.metrics import mean_absolute_error
          from skimage.restoration import denoise_bilateral, estimate_sigma, denoise_nl_means
          import pandas as pd
          import cv2
          import skimage
```

In [152]:

```
def get_middle_slice(img):
    img_data = img.get_fdata()
    slice_2 = img_data[:, :, len(img_data[0][0])//2]
    return slice_2.reshape((256, 256))

# get paths to images
path = os.getcwd()
training_path = path + '/Data/Training'
validation_path = path + '/Data/Validation'
testing_path = path + '/Data/Testing'

# load images
img1 = nib.load(training_path + '/IBSR_01/images/analyze/IBSR_01_ana.img')
img2 = nib.load(training_path + '/IBSR_02/images/analyze/IBSR_02_ana.img')
img3 = nib.load(training_path + '/IBSR_03/images/analyze/IBSR_03_ana.img')
img4 = nib.load(training_path + '/IBSR_04/images/analyze/IBSR_04_ana.img')
img5 = nib.load(training_path + '/IBSR_05/images/analyze/IBSR_05_ana.img')
img6 = nib.load(training_path + '/IBSR_06/images/analyze/IBSR_06_ana.img')
img7 = nib.load(validation_path + '/IBSR_07/images/analyze/IBSR_07_ana.img')
img8 = nib.load(testing_path + '/IBSR_08/images/analyze/IBSR_08_ana.img')
img9 = nib.load(testing_path + '/IBSR_09/images/analyze/IBSR_09_ana.img')
img10 = nib.load(testing_path + '/IBSR_10/images/analyze/IBSR_10_ana.img')
img11 = nib.load(testing_path + '/IBSR_11/images/analyze/IBSR_11_ana.img')
img12 = nib.load(testing_path + '/IBSR_12/images/analyze/IBSR_12_ana.img')
img13 = nib.load(testing_path + '/IBSR_13/images/analyze/IBSR_13_ana.img')
img14 = nib.load(testing_path + '/IBSR_14/images/analyze/IBSR_14_ana.img')
img15 = nib.load(validation_path + '/IBSR_15/images/analyze/IBSR_15_ana.img')
img16 = nib.load(testing_path + '/IBSR_16/images/analyze/IBSR_16_ana.img')
img17 = nib.load(testing_path + '/IBSR_17/images/analyze/IBSR_17_ana.img')
img_array = np.array([img1, img2, img3, img4, img5, img6, img7, img8, img9, img10,
                      img11, img12, img13, img14, img15, img16, img17])

img_seg1 = nib.load(training_path + '/IBSR_01/segmentation/analyze/IBSR_01_seg_ana.img')
img_seg2 = nib.load(training_path + '/IBSR_02/segmentation/analyze/IBSR_02_seg_ana.img')
img_seg3 = nib.load(training_path + '/IBSR_03/segmentation/analyze/IBSR_03_seg_ana.img')
img_seg4 = nib.load(training_path + '/IBSR_04/segmentation/analyze/IBSR_04_seg_ana.img')
img_seg5 = nib.load(training_path + '/IBSR_05/segmentation/analyze/IBSR_05_seg_ana.img')
img_seg6 = nib.load(training_path + '/IBSR_06/segmentation/analyze/IBSR_06_seg_ana.img')
img_seg7 = nib.load(validation_path + '/IBSR_07/segmentation/analyze/IBSR_07_seg_ana.img')
img_seg15 = nib.load(validation_path + '/IBSR_15/segmentation/analyze/IBSR_15_seg_ana.img')
img_seg_array = np.array([img_seg1, img_seg2, img_seg3, img_seg4, img_seg5, img_seg6, img_seg7, img_
seg15])

training_images, training_segments = [], []
validation_images, validation_segments = [], []
testing_images = []

for i in range(0, 6):
    training_images.append(get_middle_slice(img_array[i]))
for i in [6, 14]:
    validation_images.append(get_middle_slice(img_array[i]))
for i in [7, 8, 9, 10, 11, 12, 13, 15, 16]:
    testing_images.append(get_middle_slice(img_array[i]))
for i in range(len(img_seg_array)):
    if i < 6:
        training_segments.append(get_middle_slice(img_seg_array[i]))
    else:
        validation_segments.append(get_middle_slice(img_seg_array[i]))
```

In [126]:

```python
def transform(moving_img, scale_x, scale_y, angle, t_c, t_r, grid_size):
    h, w = moving_img.shape[0], moving_img.shape[1]
    o_h, o_w = grid_size[0], grid_size[1]

    shift_y, shift_x, temp = (np.array((o_h, o_w, 1)) - 1) / 2.
    shift_first = skimage.transform.SimilarityTransform(translation=[-shift_x, -shift_y])
    shift_back = skimage.transform.SimilarityTransform(translation=[shift_x, shift_y])

    affine = AffineTransform(scale = (scale_x, scale_y), rotation = np.deg2rad(angle), translation = (t_r, t_c))
    transformed_img = warp(moving_img, (shift_first + affine + shift_back).inverse, order=1, clip=False, preserve_range=True)
    return transformed_img
```

In [127]:

```python
def loss_MSE(parameters, moving_img, fixed_img):
    transformed_img = transform(moving_img, *parameters, fixed_img.shape)
    temp1 = np.array(fixed_img).flatten()
    temp2 = np.array(transformed_img).flatten()
    loss = np.sum(np.power(temp1-temp2, 2))
    return loss

def loss_MAE(parameters, moving_img, fixed_img):
    transformed_img = transform(moving_img, *parameters, fixed_img.shape)
    temp1 = np.array(fixed_img).flatten()
    temp2 = np.array(transformed_img).flatten()
    loss = mean_absolute_error(temp1, temp2)
    return loss

def loss(parameters, moving_img, fixed_img):
    transformed_img = transform(moving_img, *parameters, fixed_img.shape)
    output = skimage.measure.compare_ssim(skimage.color.rgb2gray(transformed_img), skimage.color.rgb2gray(fixed_img))
    return -output
```

In [128]:

```python
def optimize(fixed_img, moving_img):
    optimized_params = scipy.optimize.minimize(loss, (1,1,0,0,0), args = (fixed_img,moving_img), method = 'BFGS')
    optimized_img = transform(moving_img, *optimized_params.x, fixed_img.shape)
    return optimized_params.x, optimized_img
```

In [129]:

```python
def geometricRegistration(fixed_img, moving_img):
    height, width = fixed_img.shape[0], fixed_img.shape[1]
    normalizedImg = np.zeros((height,width))
    normalized_fixed_img = cv2.normalize(fixed_img,  normalizedImg, 0, 255, cv2.NORM_MINMAX)
    normalizedImg = np.zeros((height,width))
    normalized_moving_img = cv2.normalize(moving_img,  normalizedImg, 0, 255, cv2.NORM_MINMAX)
    opt_params, transf_img = optimize(normalized_fixed_img,normalized_moving_img)
    return opt_params, transf_img
```

In [130]:

```python
def filter_moving_imgs(moving_img):
    sigma_est = estimate_sigma(moving_img, multichannel=False, average_sigmas=True)
    moving_img = denoise_nl_means(moving_img, sigma = 1.0)
    return moving_img
```

In [131]:

```python
for i in range(len(training_images)):
    training_images[i] = filter_moving_imgs(training_images[i])
    print(i) # keep track of progress
for i in range(len(validation_images)):
    validation_images[i] = filter_moving_imgs(validation_images[i])
    print(i) # keep track of progress
```

```
0
1
2
3
4
5
0
1
```

In [132]:

```
training_opt_params, val_opt_params = [], []
count = 0
for fixed_img in testing_images:
    print(count)
    for moving_img in training_images:
        op, tf = geometricRegistration(fixed_img, moving_img)
        training_opt_params.append(op)
    for moving_img in validation_images:
        op, tf = geometricRegistration(fixed_img, moving_img)
        val_opt_params.append(op)
    count += 1
```

In [133]:

```
seg_0 = [transform(training_segments[i], *training_opt_params[i], testing_images[0].shape) for i in range(6)]
seg_1 = [transform(training_segments[i], *training_opt_params[6+i], testing_images[1].shape) for i in range(6)]
seg_2 = [transform(training_segments[i], *training_opt_params[12+i], testing_images[2].shape) for i in range(6)]
seg_3 = [transform(training_segments[i], *training_opt_params[18+i], testing_images[3].shape) for i in range(6)]
seg_4 = [transform(training_segments[i], *training_opt_params[24+i], testing_images[4].shape) for i in range(6)]
seg_5 = [transform(training_segments[i], *training_opt_params[30+i], testing_images[5].shape) for i in range(6)]
seg_6 = [transform(training_segments[i], *training_opt_params[36+i], testing_images[6].shape) for i in range(6)]
seg_7 = [transform(training_segments[i], *training_opt_params[42+i], testing_images[7].shape) for i in range(6)]
seg_8 = [transform(training_segments[i], *training_opt_params[48+i], testing_images[8].shape) for i in range(6)]

segv_0 = [transform(validation_segments[i], *val_opt_params[i], testing_images[0].shape) for i in range(2)]
segv_1 = [transform(validation_segments[i], *val_opt_params[i+2], testing_images[0].shape) for i in range(2)]
segv_2 = [transform(validation_segments[i], *val_opt_params[i+4], testing_images[0].shape) for i in range(2)]
segv_3 = [transform(validation_segments[i], *val_opt_params[i+6], testing_images[0].shape) for i in range(2)]
segv_4 = [transform(validation_segments[i], *val_opt_params[i+8], testing_images[0].shape) for i in range(2)]
segv_5 = [transform(validation_segments[i], *val_opt_params[i+10], testing_images[0].shape) for i in range(2)]
segv_6 = [transform(validation_segments[i], *val_opt_params[i+12], testing_images[0].shape) for i in range(2)]
segv_7 = [transform(validation_segments[i], *val_opt_params[i+14], testing_images[0].shape) for i in range(2)]
segv_8 = [transform(validation_segments[i], *val_opt_params[i+16], testing_images[0].shape) for i in range(2)]

reg_segs0 = np.zeros((8, 256, 256))
reg_segs1 = np.zeros((8, 256, 256))
reg_segs2 = np.zeros((8, 256, 256))
reg_segs3 = np.zeros((8, 256, 256))
reg_segs4 = np.zeros((8, 256, 256))
reg_segs5 = np.zeros((8, 256, 256))
reg_segs6 = np.zeros((8, 256, 256))
reg_segs7 = np.zeros((8, 256, 256))
reg_segs8 = np.zeros((8, 256, 256))

for i in range (6):
    reg_segs0[i,:,:] = seg_0[i]
    reg_segs1[i,:,:] = seg_1[i]
    reg_segs2[i,:,:] = seg_2[i]
    reg_segs3[i,:,:] = seg_3[i]
    reg_segs4[i,:,:] = seg_4[i]
    reg_segs5[i,:,:] = seg_5[i]
    reg_segs6[i,:,:] = seg_6[i]
    reg_segs7[i,:,:] = seg_7[i]
    reg_segs8[i,:,:] = seg_8[i]

for i in range (2):
    reg_segs0[i+6,:,:] = segv_0[i]
    reg_segs1[i+6,:,:] = segv_1[i]
    reg_segs2[i+6,:,:] = segv_2[i]
    reg_segs3[i+6,:,:] = segv_3[i]
    reg_segs4[i+6,:,:] = segv_4[i]
    reg_segs5[i+6,:,:] = segv_5[i]
    reg_segs6[i+6,:,:] = segv_6[i]
    reg_segs7[i+6,:,:] = segv_7[i]
    reg_segs8[i+6,:,:] = segv_8[i]
```

In [142]:

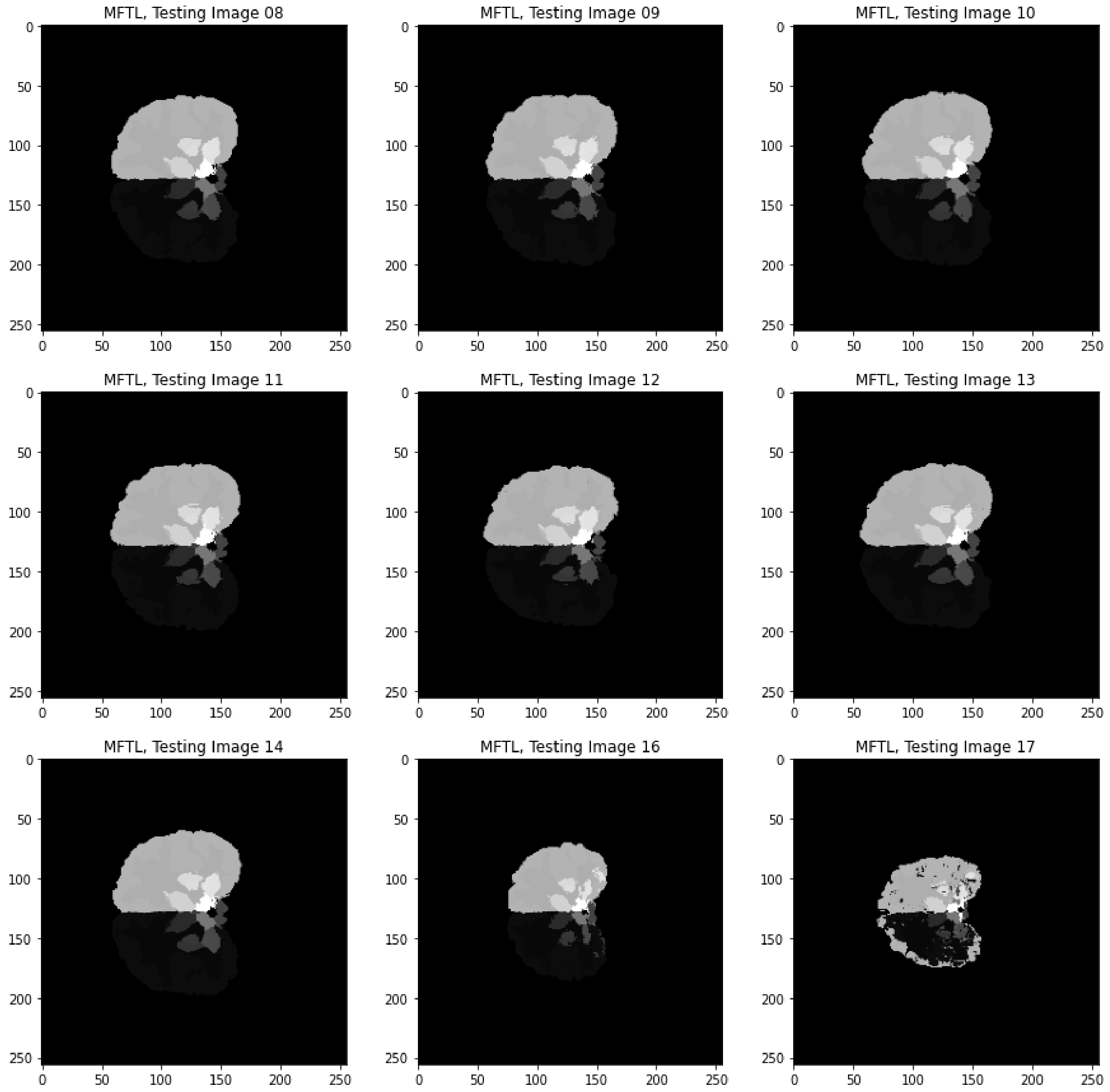
```
def MFTL(imgs):
    modes = np.zeros((256,256))

    for i in range(len(imgs[0])):
        for j in range(len(imgs[0][0])):
            m, count = mode([imgs[x][i][j] for x in range(len(imgs))])
            if count == 1 or m == 0:
                if count == 1:
                    m = np.sum([imgs[x][i][j] for x in range(len(imgs))])//8
                else:
                    if count < 4:
                        m = np.max([imgs[x][i][j] for x in range(len(imgs))])
            modes[i][j] = m
    return modes

def MFTL_v0(imgs):
    modes, count = mode(imgs) # Default is axis=0, don't care about count output
    modes = modes.reshape((256, 256))

    return modes
```

In [135]:

```
segs = [reg_segs0, reg_segs1, reg_segs2, reg_segs3,
        reg_segs4, reg_segs5, reg_segs6, reg_segs7, reg_segs8]
MFTLs = []
for seg in segs:
    MFTLs.append(MFTL(seg))
```

In [136]:

```
figcount = 1
label = ['08','09','10','11','12','13','14','16','17']
w = 10
h = 10
fig = plt.figure(figsize = (15, 15))
columns = 3
rows = 3
for i in range(1, columns*rows +1):
    fig.add_subplot(rows, columns, i)
    plt.title('MFTL, Testing Image ' + label[i-1])
    plt.imshow(MFTLs[i-1].squeeze(), cmap = 'gray')
plt.show()
fig.savefig('MFTL.png')
```



In [137]:

```
# for kaggle
def format_seg(img):
    img = np.array(img)
    temp1 = np.zeros(img.shape)
    temp1[img == 2] = 1

    temp2 = np.zeros(img.shape)
    temp2[img == 3] = 1

    temp3 = np.zeros(img.shape)
    temp3[img == 41] = 1

    temp4 = np.zeros(img.shape)
    temp4[img == 42] = 1

    return np.array((temp1, temp2, temp3, temp4))

def rle_encode(img):
    '''
    img: numpy array, 1 - mask, 0 - background
    Returns run length as string formated
    '''
    pixels = img.flatten()
    pixels = np.concatenate([[0], pixels, [0]])
    runs = np.where(pixels[1:] != pixels[:-1])[0] + 1
    runs[1::2] -= runs[::2]
    return ' '.join(str(x) for x in runs)
```

In [123]:

```
masks2, masks3, masks41, masks42 = [], [], [], []

for MFTL in MFTLs:
    masks = format_seg(MFTL)
    masks2.append(masks[0])
    masks3.append(masks[1])
    masks41.append(masks[2])
    masks42.append(masks[3])

data = []
for i in range(9):
    data.append(rle_encode(masks2[i]))
    data.append(rle_encode(masks3[i]))
    data.append(rle_encode(masks41[i]))
    data.append(rle_encode(masks42[i]))

# labels
regions = ['-left-wm', '-left-cortex', '-right-wm', '-right-cortex']
nums = ['8','9','10','11','12','13','14','16','17']
labels = []

for num in nums:
    for reg in regions:
        labels.append(num + reg)

df = pd.DataFrame({"Id": labels, "Predicted": data})
df.to_csv('submission.csv', index = False)
```

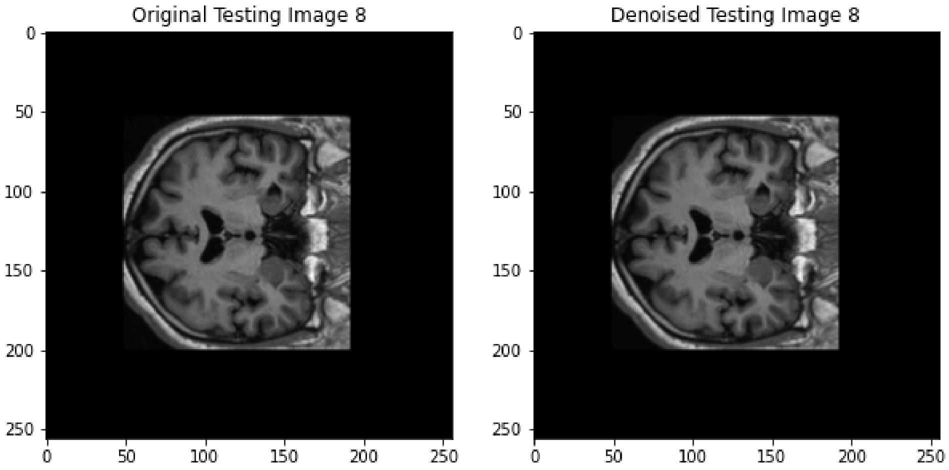
In [138]:

```
# some plots for the paper
sigma_est = estimate_sigma(testing_images[0], multichannel=False, average_sigmas=True)
print(sigma_est)
moving_img = denoise_bilateral(testing_images[0], sigma_color = 1.0, multichannel=False)
moving_img1 = denoise_nl_means(testing_images[0], sigma = 1.0)
```

```
1.272448061995835
```

In [98]:

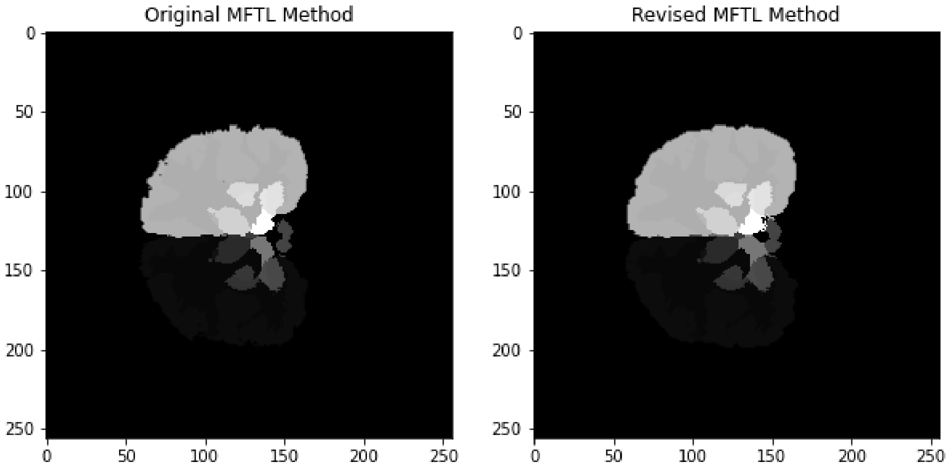
```
fig = plt.figure(figsize = (10, 10))
fig.add_subplot(121)
plt.title('Original Testing Image 8')
plt.imshow(testing_images[0].squeeze(), cmap = 'gray')

fig.add_subplot(122)
plt.title('Denoised Testing Image 8')
plt.imshow(moving_img1.squeeze(), cmap = 'gray')

fig.savefig('filter.png')
```


Original Testing Image 8

Denoised Testing Image 8

In [143]:

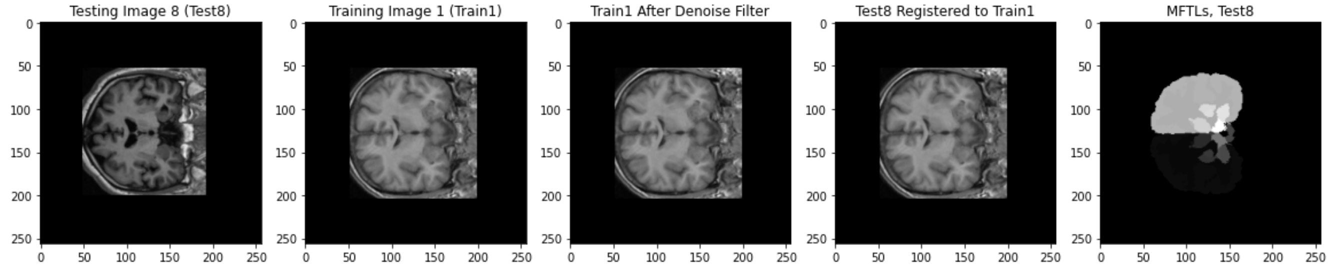
```
fig = plt.figure(figsize = (10, 10))
fig.add_subplot(121)
plt.title('Original MFTL Method')
plt.imshow(MFTL_v0(segs[0]).squeeze(), cmap = 'gray')

fig.add_subplot(122)
plt.title('Revised MFTL Method')
plt.imshow(MFTL(segs[0]).squeeze(), cmap = 'gray')

fig.savefig('comp_MFTL.png')
```


Original MFTL Method

Revised MFTL Method

In [151]:

```
fig = plt.figure(figsize = (20, 20))
fig.add_subplot(151)
plt.title('Testing Image 8 (Test8)')
plt.imshow(testing_images[0].squeeze(), cmap = 'gray')

fig.add_subplot(152)
plt.title('Training Image 1 (Train1)')
plt.imshow(get_middle_slice(img1).squeeze(), cmap = 'gray')

fig.add_subplot(153)
plt.title('Train1 After Denoise Filter')
plt.imshow(training_images[0].squeeze(), cmap = 'gray')

fig.add_subplot(154)
plt.title('Test8 Registered to Train1')
plt.imshow(training_images[0].squeeze(), cmap = 'gray')

fig.add_subplot(155)
plt.title('MFTLs, Test8')
plt.imshow(MFTLs[0].squeeze(), cmap = 'gray')

fig.savefig('totalimg.png')
```



Testing Image 8 (Test8)

Training Image 1 (Train1)

Train1 After Denoise Filter

Test8 Registered to Train1

MFTLs, Test8

In [ ]: