Motion correction of contrast-enhanced MRI time series of kidney

Peter Rogelj[1], Frank G. Zöllner[2,3], Stanislav Kovačič[1], Arvid Lundervold[2]

[1] *Faculty of Electrical Engineering, University of Ljubljana, Slovenia*
[2] *Department of Biomedicine, University of Bergen, Norway*
[3]*Department of Surgical Sciences, University of Bergen, Norway*
E-mail: peter.rogelj@fe.uni-lj.si

Abstract

In this paper we focus on motion correction of contrast enhanced kidney MRI time series, which is an important step towards accurate assessment of regional renal function. Due to respiratory motion and pulsations, the organ of interest undergoes complex movement and deformation, which disturb further renal function analysis. We propose geometric movement correction by image registration. We have compared rigid and nonrigid registration methods as well as registration of whole images and registration limited to ROI that defines the organ under investigation. The obtained results show that image registration methods benefit to renal function analysis, i.e. to the assessment of intensity time courses. Furthermore, the comparison of the registration methods shows benefits of ROI limited methods and eventual problems of nonrigid methods.

Keywords: motion correction, image registration, contrast-enhanced MRI.

1 Introduction

The kidneys maintain normal homeostasis by filtering and excreting metabolic waste products, by regulating acid-base balance and by moderating blood pressure and fluid volume. A decrease in renal function is caused by many disorders, among these diabetes mellitus and hypertension. Chronic renal failure is an increasing problem world-wide; up to 5% of the world's population may in the near future suffer from end-stage renal disease (ESRD), with dialysis or kidney transplantation as the costly therapeutic alternatives. It is thus important, for patients and society, that methods are developed to monitor renal function precisely, thus enhancing the assessment of disease progression, the prognosis and follow-up therapy.

At present, diagnosis of renal dysfunction is based on indirect measurements (such as measurements of creatinine, urea, and electrolytes), which have low sensitivity; such that a significant change is only detectable after a 60% function loss has occurred. In addition, these clinical chemistry measurements cannot detect local differences in the kidneys and cannot distinguish between left and right kidney. To overcome these limitations, dynamic contrast-enhanced MR imaging (DCE-MRI) has emerged as a technique that can be used for the more accurate assessment of regional renal function [1,2]. With this technique, signal intensity evolution can be measured and visualized as images that reflect the passage of an injected tracer or contrast agent through the organ.

An important problem of measurement techniques that are based on sequential imaging is movement of organs during image acquisitions. In our case, kidneys are subjected to complex displacements due to respiratory motion and pulsations. Such movements are often overlooked in studies of renal function. However, without proper motion correction, the derived voxel time courses will not represent spatially fixed kidney volume elements, assumed by subsequent voxel-based time series analysis and pharmacokinetic modeling.

In this paper we focused on geometrical correction of images for movements and deformations, using image registration techniques. We compared four methods, which differ according to rigidity and according to the spatial extent of the geometrical correction.

2 Image registration

For a survey on image registration see [3]. Our case, motion correction of contrast-enhanced image time series, is a special case of image registration, because there are two types of motion and deformation present and visible in the images. The first type is motion and deformation of tissues as a result of e.g. breathing, while the second is motion of the contrast agent. In order to correct for motion resulting from breathing and pulsations, the registration method needs to be unaffected by intensity changes caused by the accumulation and excretion of the contrast agent.

We focus on multi-modality registration techniques, which enable the registration of images with complex intensity dependencies, e.g., of images acquired with different imaging techniques. In our case, these approaches provide the invariance to the presence and flow of the contrast agent. Thus, individual images of the time series can be independently registered on the selected reference frame, without using any temporal constraints. This ensures that temporal information is not distorted, which is important, since temporal information is later used for the analysis of renal function. We have compared four types of multi-modality image registration:

- rigid registration,
- non-rigid registration,
- ROI-limited rigid registration,
- ROI-limited non-rigid registration.

All the methods were implemented within the same framework, which is schematically illustrated in Fig.1.

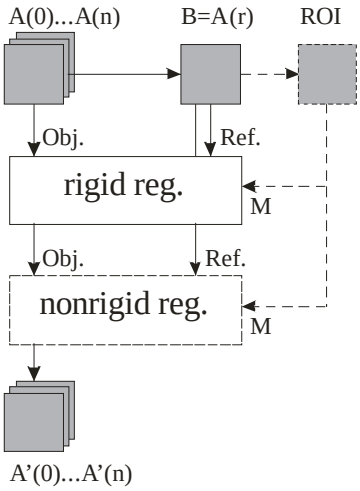


Figure 1: Image registration methods for geometrical correction of movements and deformations of image time series. Dotted lines represent optional components.

The process of correcting movements and deformations by image registration independently registers each of the images A(i), where i corresponds to the image frame number in a time series, to the same reference image B. The result are registered images A'(i). The overall process consists of the following steps:

- selection of the reference image,
- (optional) definition of ROI,
- rigid registration,
- (optional) nonrigid registration.

Selection of the reference image B is important, because not all of the images in the time series A enable differentiation among kidney regions. In addition, some of the images are often corrupted or highly deformed due to the intense breathing movements. In our study we selected the reference image B from images A within the wash-in part of the series for the renal cortex, which is for a healthy patient at about 15-20 seconds after injection.

Breathing highly affects position of internal organs. Movement of kidneys is complex, although the spine, which lies close in the neighborhood, is rigid and fixed. Registration method must be able to deal with such complex geometrical changes. Consequently, rigid registration of the whole images is not optimal, and other approaches must be used. Possible solutions include the use of nonrigid registration approaches or definition of region of interest (ROI) that localizes the registration. In our study ROIs were defined manually, by approximately outlining the kidneys in all slices of the reference image.

Rigid registration, used in our study was performed by optimizing global/regional image similarity, computed by point similarity measure S_{UH} [4]. The detailed description of the method is given in [5].

Optional nonrigid registration is high-dimensional and is also based on point similarity measure S_{UH}. For the detailed description of the nonrigid method see [4].

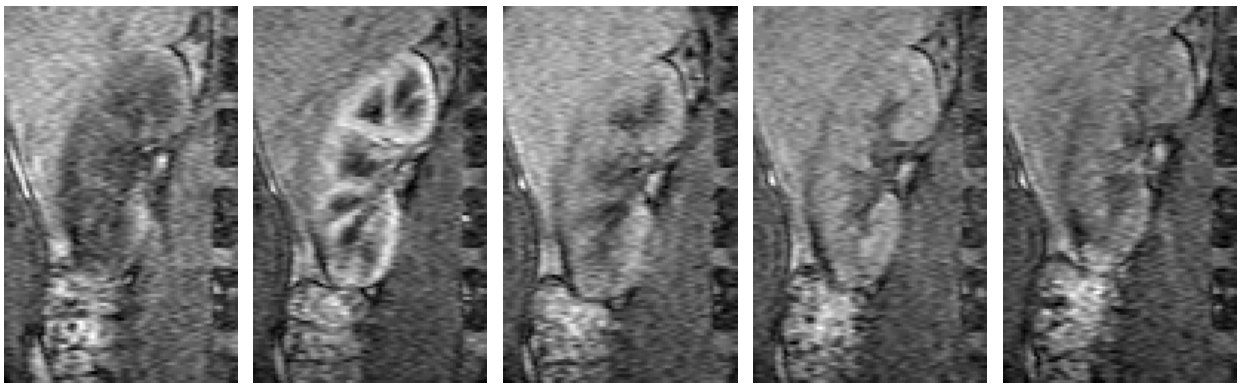
When ROIs are used, they affect both, rigid as well as nonrigid registration. In rigid registration they are used in a way of limiting the computation of criterion function only to the region defined by ROI. Consequently, other regions cannot be expected to become correctly registered. In non-rigid registration ROI only defines the region used for computing point similarity functions, in order to reduce the influence of other regions, with eventually different intensity properties.

3 Experiments

The experiments were performed on one image dataset, acquired using a Siemens Magnetom Symphony imaging device (field strength 1.5T) and a T1 weighted 3D VIBE sequence with 1.48x1.48x3.8 mm spatial resolution, TR=3.3 ms, TE=1.79 ms, FA=9.0 degree. The dimension of the dataset is 256x256x22x105, with temporal resolution 2.8 sec/3D-image. The contrast agent (2 ml Magnevist) was injected with an automatic injector after 5 acquired images.

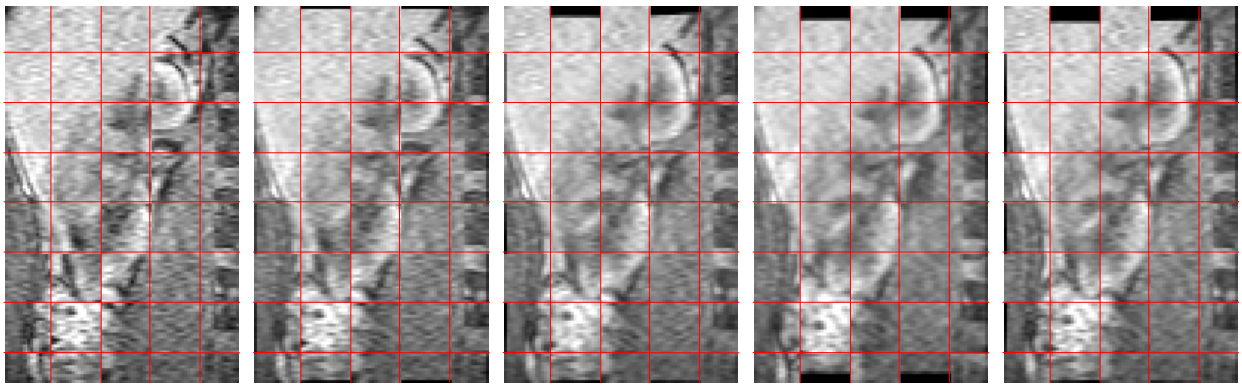
The data was registered with all four methods described in the previous section, using image frame number 16 for the reference and manually defined ROI for the kidney region. In all cases left and right kidney were registered independently, although they are imaged together. Some examples of input images are shown in Fig. 2. It is clearly seen how the contrast agent passes through renal compartments; starting in the renal cortex and passing though the medulla. The geometrical differences, which need to be removed, are in these images difficult to notice. To illustrate these differences and the results obtained with the four registration methods, the checker board images are shown in Fig. 3. In all the cases (a-e) the checker board images consist of frame 24 and frame 29, which are similar in contrast distribution (intensities) and considerably differ in geometry. The geometrical differences are the most obvious at the top of the kidney and also at the lower left side of the kidney. It is evident that rigid registration (Fig 3.b) is not capable of correcting all geometrical differences in the kidney region. It tends to find optimal alignment of the whole images, but due to different movement and deformation of different anatomical regions, large geometrical differences remain all over the images. An additional nonrigid registration (Fig 3.c) improves the results, such that images become visually well aligned.

When using ROI to limit the registration to the kidney region only, results for the rigid registration improve considerably (Fig 3.d). The kidney region seems to be aligned correctly, although some neighboring tissues, which are not in our interest, are clearly misaligned.



i=0 i=16 i=32 i=64 i=104

Figure 2: Input images for different frames of the image data series. Image at frame i=0 represents the initial image without the contrast agent, i=16 corresponds to the wash-in for the renal cortex and is used as a reference, frames i=32,64 and 104 show further passage of the contrast agent through the kidney. In all the cases only the central slice of a 3D image is shown.



(a) (b) (c) (d) (e)

Figure 3: Checker board images (central slices) for frames 24 and 29 before registration (a) after rigid registration (b), nonrigid registration (c), ROI-limited rigid registration (d) and ROI-limited nonrigid registration.

The kidneys seem to behave as a rigid body, i.e., they move with respect to the other organs, while their deformation is not noticeable. ROI-limited nonrigid registration (Fig 3.e) makes only minor additional changes in the kidney region, when compared to the ROI-limited rigid registration (Fig 3.d). The improvements are obvious in the neighboring regions, which are not of our interest. However, some neighboring regions are still not optimally registered, which is due to their different intensity properties, compared to those for the kidney region. By adapting similarity measurement only to intensity properties of the kidney region, the matching inside the region can improve, sacrificing the correctness in the other parts of the image.

In the next experiment the registration results were analyzed by comparing intensity profiles obtained for small regions inside the kidney, see Fig. 4. Intensity profiles show the change of mean region intensity through time. It is assumed that the change of intensity is only due to different amounts of contrast agent in the observed region. In practice, the differences are also due to spatial misalignment, which cause the same image point/region to belong to a different anatomical point/region in the anatomy. Such misalignments cause errors in estimation of intensity profiles, including sharp peaks, such as those visible in Fig.4, frame numbers 26, 44, 61, 78 and 95. Images at these frames are more difficult to register, because they are distorted due to intense breathing movements of the patient. In contrast to the previously mentioned peaks, a peak of intensity profile for region R1 (cortex) at frame 16 is not an error. It corresponds to the wash-in of the renal cortex and should be clearly expressed. Profile for the region R2 (medulla) should have lower dynamics, and no expressed peaks (for the healthy patients).

The intensity profiles for different registration methods, depicted in Fig.4, support the findings described above. Profiles for rigid registration are similar to the profiles for the unregistered data, with the exception of reduced oscillations around frame 80. The nonrigid registration shows only slight additional improvements. Both ROI-limited registrations gain more improvements in comparison to the unregistered data. This is especially obvious inspecting the peak at frame 95, which is in case of ROI-limited registration correctly suppressed. The most of the oscillations are suppressed in profiles for ROI-limited rigid registration.

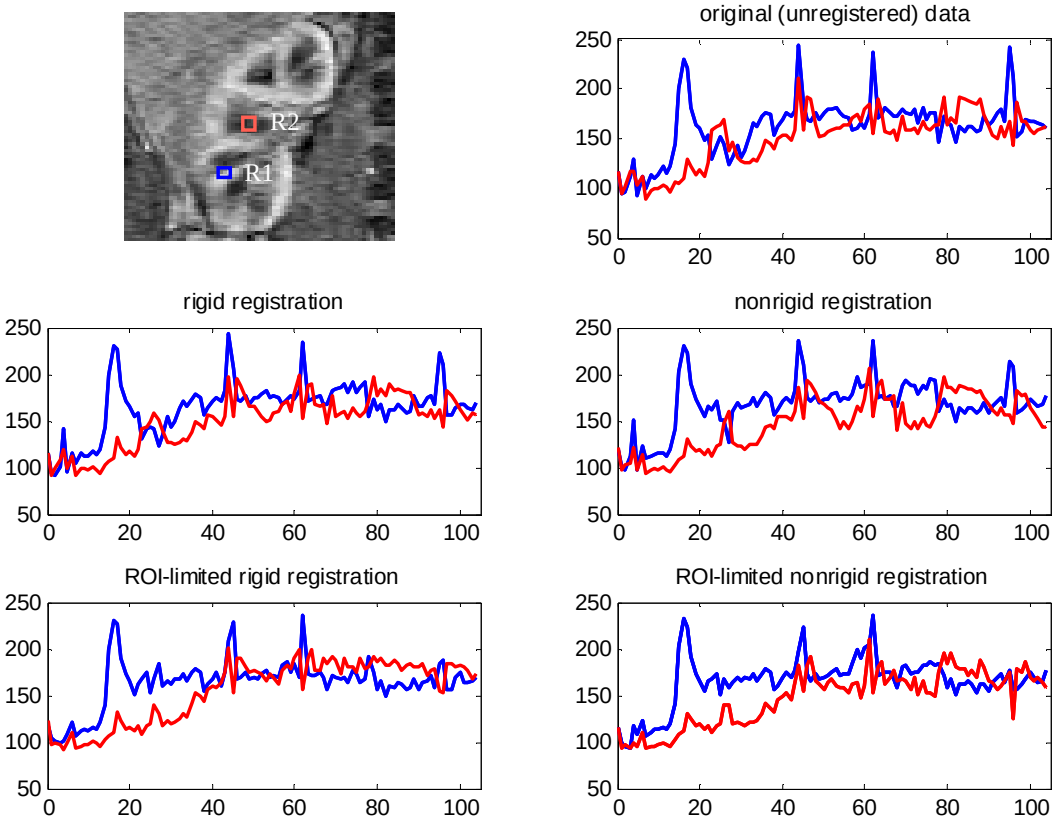


Figure 4: Comparison of intensity profiles for original (unregistered) data and all compared registration methods. The curves show the mean intensity value of two small regions (shown in upper left), with respect to the frame number.

4 Discussion and conclusion

In general, it is expected that nonrigid registration methods are better than rigid ones, because they can correct not only global, but also local geometrical differences. In our case this ability of nonrigid registration is not necessarily advantageous. The reason is due to two kinds of movements and deformations present in this study: geometrical differences of the anatomy and passage of the contrast agent through the anatomy. In order to correctly register the anatomy, only the first one must be considered, while the second one should be suppressed. To do that, some method of differentiation between both components must be used, and this requires sprior knowledge. In our experiment this prior knowledge has a geometrical nature and is provided by the assumption of kidney rigidity, used by ROI-limited registration methods. The results show that this assumption is useful, although it may not be absolutely correct.

Motion correction of DCE-MRI time series shown in this paper is sufficiently accurate to successfully analyze kidney function. However, the accuracy can still be improved by finding better methods for discrimination between both kinds of movements.

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