# Deformable Registration with *syngo*.via

## RT Image Suite

**Case study: Contouring based on CT and PET/CT imaging in head & neck cancer patient**

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# Content

# Introduction

A head & neck cancer (HNC) patient was referred to the Radiation Oncology Department of the University Hospital, Tübingen (Germany) for primary radiation therapy with concomitant chemotherapy. Contouring of the RT target volumes and organs-at-risk (OARs) was performed using the planning CT and the [18F]-FDG stating PET/CT imaging data.

# Purpose

The purpose of this publication is to evaluate the accuracy of deformable registration in this case. In addition, the technical details of the deformable registration used in *syngo*.via RT image Suite are described.

# The image registration workflow in *syngo*.via RT Image Suite

## Rigid registration

First, *syngo*.via RT Image Suite calculates the rigid registration between the planning CT and the PET/CT to recover the global alignment of the data sets – this is performed automatically upon loading the image data sets into the software. All further navigation through the images is then automatically aligned and synchronized in the two data sets.

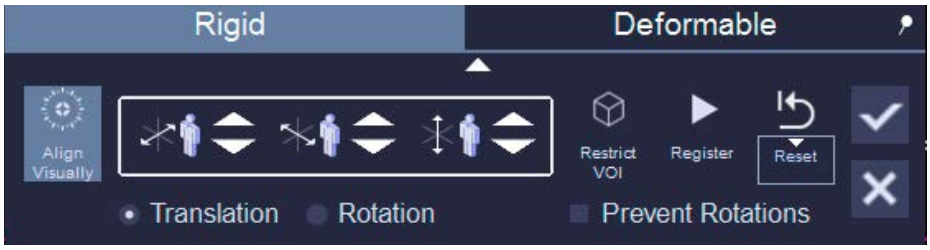


Figure 1: Control panel offers options for translational and rotational shifts of the data set in addition to visual alignment and restriction of the registration to a Volume-of-Interest (VOI).a

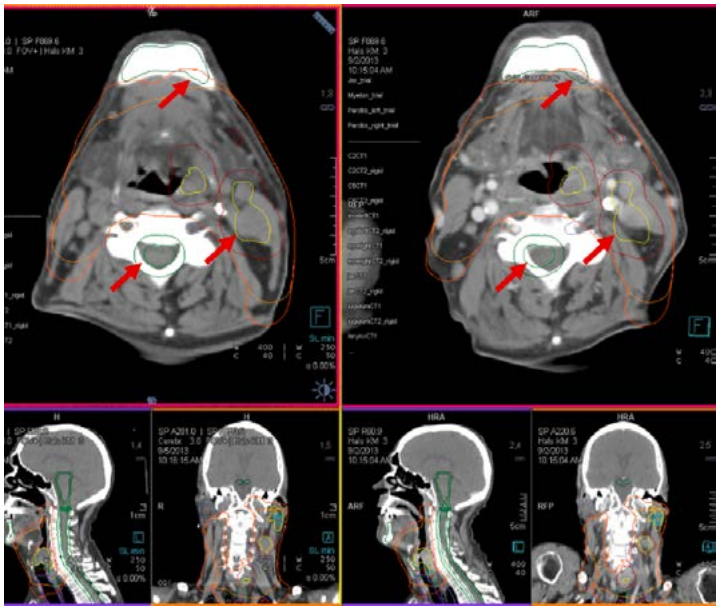

Figure 2: Rigid registration of RT planning CT (left panel) with PET/CT (right panel). Due to different patient positioning, the registration of the two image data sets still shows considerable misalignment.

It is also possible to select a Volume-of-Interest (VOI) to achieve a more accurate local rigid registration. Especially in cases where the patient position has changed significantly between the scans, e.g., one data set was acquired in the RT mask, the other one in the diagnostic position or when significant changes in anatomy (before/ after treatment) have occurred. The VOI is usually set around the tumor location to be evaluated in order to improve the accuracy of the registration in that area.

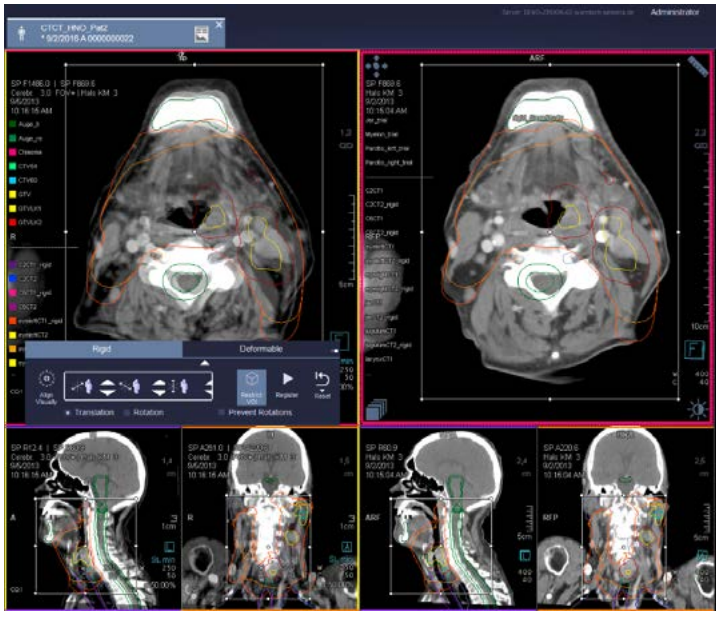


Figure 3: Visualization of the VOI used to calculate the rigid registration result.

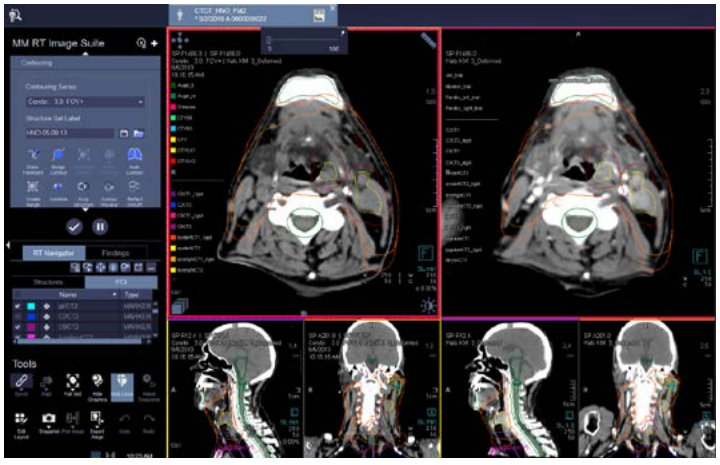


Figure 4: Result of the rigid registration restricting the image volumes to the VOI shown in Figure 3. This shows improvement in the alignment of bony structures and tumor.

## Deformable registration

In head and neck cases, the patient position often varies between the planning CT scan (with immobilization devices) and the PET/CT scan (without immobilization devices). Rigid registration mechanisms might not be able to cope with the non-rigid changes , and here the deformable registration available in *syngo*.via RT Image Suite[1] has proven beneficial.

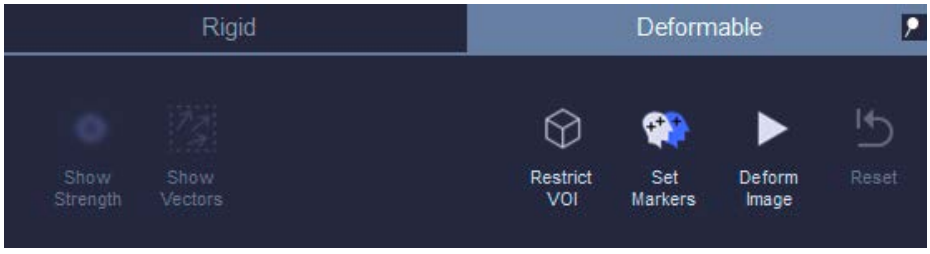


Figure 5: Control panel to guide the deformable image registration.

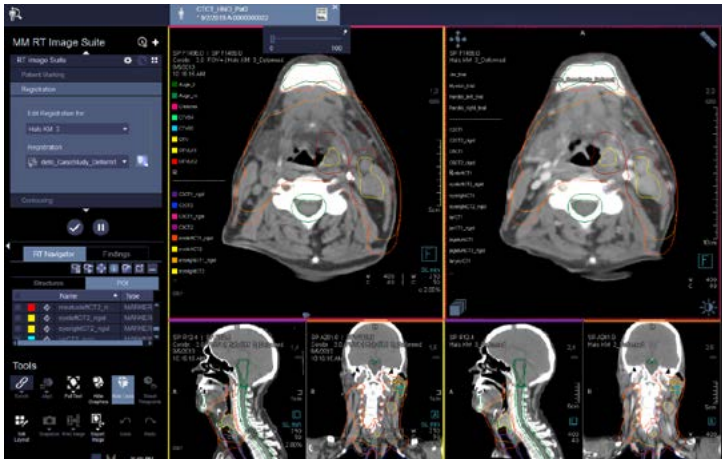


Figure 6: Result of deformable registration without additional refinement.

*syngo*.via RT Image Suite also supports deformable registration in a specific VOI, which is recommended in cases where the positioning of the patient strongly differs between the two scans (e.g., planning CT on a flat tabletop with a thermoplastic mask and a diagnostic PET/CT on a curved table without a mask).

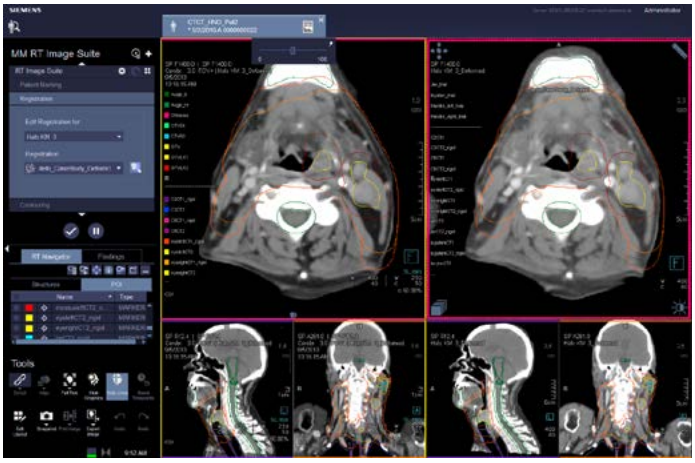


Figure 7: Result of VOI-based deformable registration.

Furthermore, if there is still residual misalignment in the data, *syngo*.via RT Image Suite allows specifying landmarks to refine the registration.

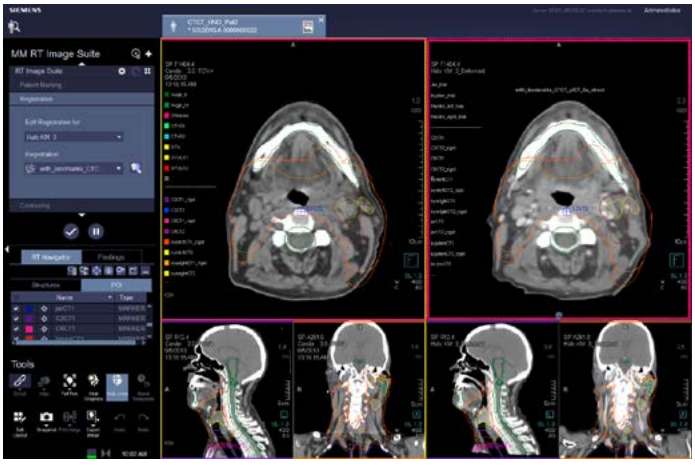


Figure 8: Result of the deformable registration using four anatomical landmarks to guide the registration (cf. note the landmark is shown on the C2 vertebra.)

## Evaluation of the registration result

*syngo*.via RT Image Suite offers several options to evaluate the results of the registration:

- Assessment of the image itself via fusion (i.e., Spyglass)
- Assessment the deformation vector field
- Assessment of deformed landmarks or contours
- Export of the registration file for archiving

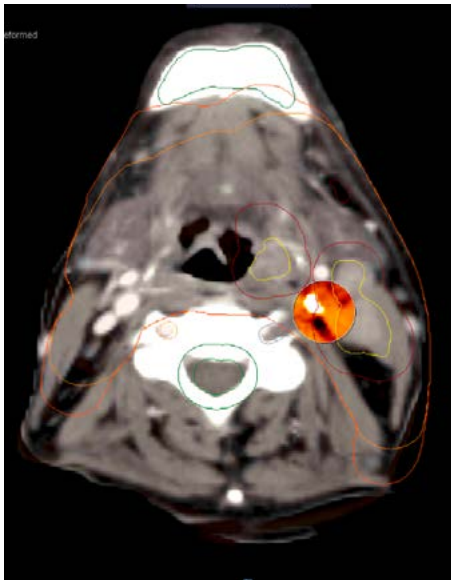

Figure 9: Spyglass option to check the alignment of the two fused data sets in different anatomical regions.

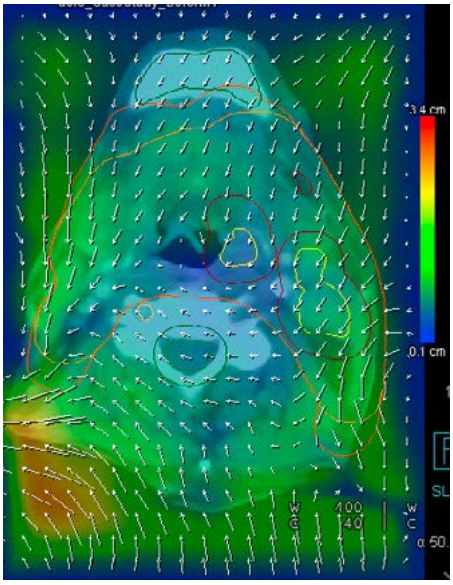


Figure 10: Deformation vector field showing strength (color-coded) and direction of image voxel displacements.

# Evaluating accuracy of the algorithm

In this case study, a radiation oncologist defined a total of five anatomical landmarks (C2, C6, jaw, jugulum, larynx) in both image data sets (RT planning CT and PET/CT) to evaluate the quality of the different registration options. The residual distances between those landmark points have been calculated for each registration step. Detailed results of the average distances between the anatomical landmarks are shown in Table 1.

| Registration method | Mean difference (SD) of anatomical landmarks [mm] |
|---|---|
| Rigid | 5.6 (1.8) |
| Deformable | 3.1 (2.1) |
| Deformable using landmarks | 3.0 (0.8) |
| Deformable VOI | 3.4 (1.4 ) |

Table 1: Mean distances between anatomical landmarks after applying different registration methods in RTiS in an example HNC case.

Furthermore a radiation oncologist contoured four exemplary structures in both CT data sets (jaw, spinal cord, left/right parotid gland). After rigid and deformable registration, the agreement between those 3-dimensional structures was compared by calculating the Dice similarity index (DSI). If two volumes match perfectly, the DSI equals 1. If the volumes do not overlap, the DSI equals 0. DSI values for the example case presented here are given in Table 2.

| Structure | DSI | |
|---|---|---|
| | Rigid | Deformable |
| Jaw | 0.59 | 0.83 |
| Spinal cord | 0.40 | 0.85 |
| Left parotid | 0.66 | 0.78 |
| Right parotid | 0.64 | 0.67 |

Table 2: DSI values between anatomical landmarks after applying different registration methods in RTiS in an example HNC case.

# Discussion

*syngo*.via RT Image Suite is an excellent tool for multi-parametric image processing and registration in the context of RT planning. Both registration methods offer 1) fully automated rigid or deformable registration, 2) semi-automated registration such as VOI-based registration, and 3) anatomical landmark-based registration. These tools allow you to skip the entire 3D image volume alignment, offering the easiest and fastest possible way to register two image data sets. In cases where the two image data sets present two different patient positions or other major discrepancies between the two image volumes (i.e., before and after treatment), the accuracy of the registration result obtained without any further interaction may not be sufficiently accurate. In this case, a VOI-based registration can be chosen, where the volume taken into account by the registration algorithm is manually defined according to the relevant anatomical structures, including tumor volume and corresponding organs at risk. If the registration result is still not acceptable, landmark-based registration is an another option. This method is the most time-consuming and needs to be carried out by experienced radiation oncologists or radiologists. The accuracy of the registration result in this case depends mainly on the quality of the anatomical landmarks.

Overall, the example case nicely shows the high accuracy of the deformable image registration algorithm implemented in *syngo*.via RT Image Suite . It was shown to be around 2.5 mm, i.e., in the order of one voxel size.

Registration results should be visually checked for each registered case by visualizing the deformation vector field (see Figure 10). Here, the direction and strength of deformation are displayed graphically. It is recommended to evaluate the deformation vector field for anatomical plausibility and especially for discontinuities in the vicinity of the tumor region.

# Conclusion

Overall, *syngo*.via RT Image Suite provides a large set of tools to perform and evaluate deformable registration.

In the case of the head & neck patient, we found that the deformable registration mode of *syngo*.via RT Image Suite was a reliable way to leverage the PET/CT staging information acquired in different treatment positions.

*syngo*.via RT Image Suite helps radiation oncology professionals leverage CT, MRI, PET/CT and CBCT images in a variety of clinical scenarios.

# The deformable registration algorithm

The deformable registration algorithm is based on a diffeomorphic non-rigid registration driven by the gradient of the local cross-correlation similarity measure[2]. In more specific terms, a similarity measure is minimized in a variational framework between the data sets so that they match voxel-by-voxel. In the case of CT-CT registration, the normalized cross-correlation similarity measure is used. The underlying deformation model is based on a free-form dense deformable field that is regularized during the optimization process resulting in a diffeomorphic vector field that matches the data sets smoothly. This approach is based on the multi-resolution strategy[2] to improve speed and robustness.

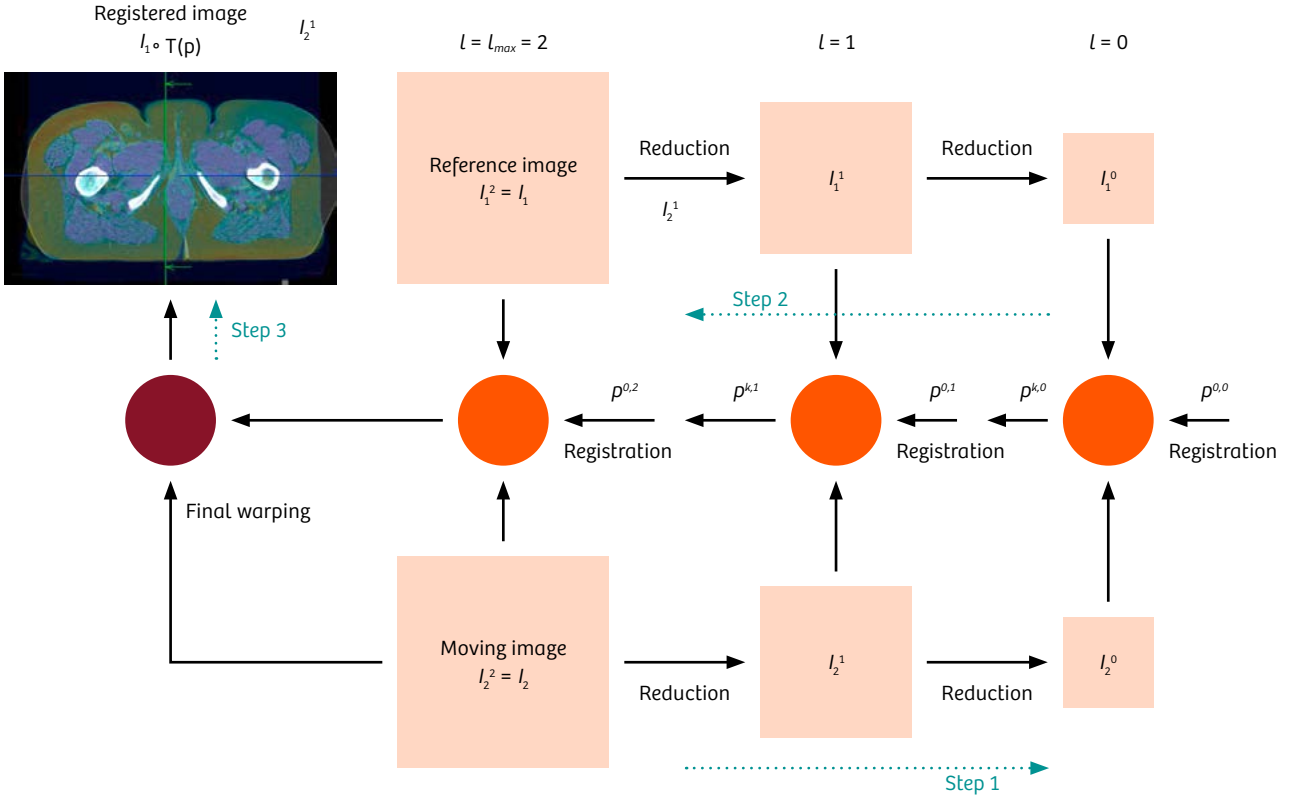


Figure 11: Illustration of the multi-resolution registration scheme(with 3 levels in this example)

In addition, the algorithm has been designed to cope with different positions of the anatomy (i.e., head bending):

- **STEP 1:** The entire image FOV of the treatment planning CT (reference image) is divided into three regions: head, neck, and body. The head, neck, and body regions are divided by anatomic landmarks of the skull base and the apices of the lungs, which can be automatically detected using a learning-based approach.
- **STEP 2:** A rigid registration is applied separately to the head and body region. For the neck region, the registration parameters are estimated by averaging the registration parameters from the head and body region. The results of separate rigid registration are shown in Figure 4.
- **STEP 3:** A diffeomorphic deformable registration [1] is also applied separately to the three regions. Overlapping areas are reserved between the three regions (see Figure 4) for smooth transition of the deformation fields from one region to another. The warped images from the three separate regions are then merged based on the dividing anatomic landmarks (the skull base, the apices of the lungs). Figure 5 shows the final output from the region-based registration: the overall result is satisfactory and the three regions are merged together seamlessly.

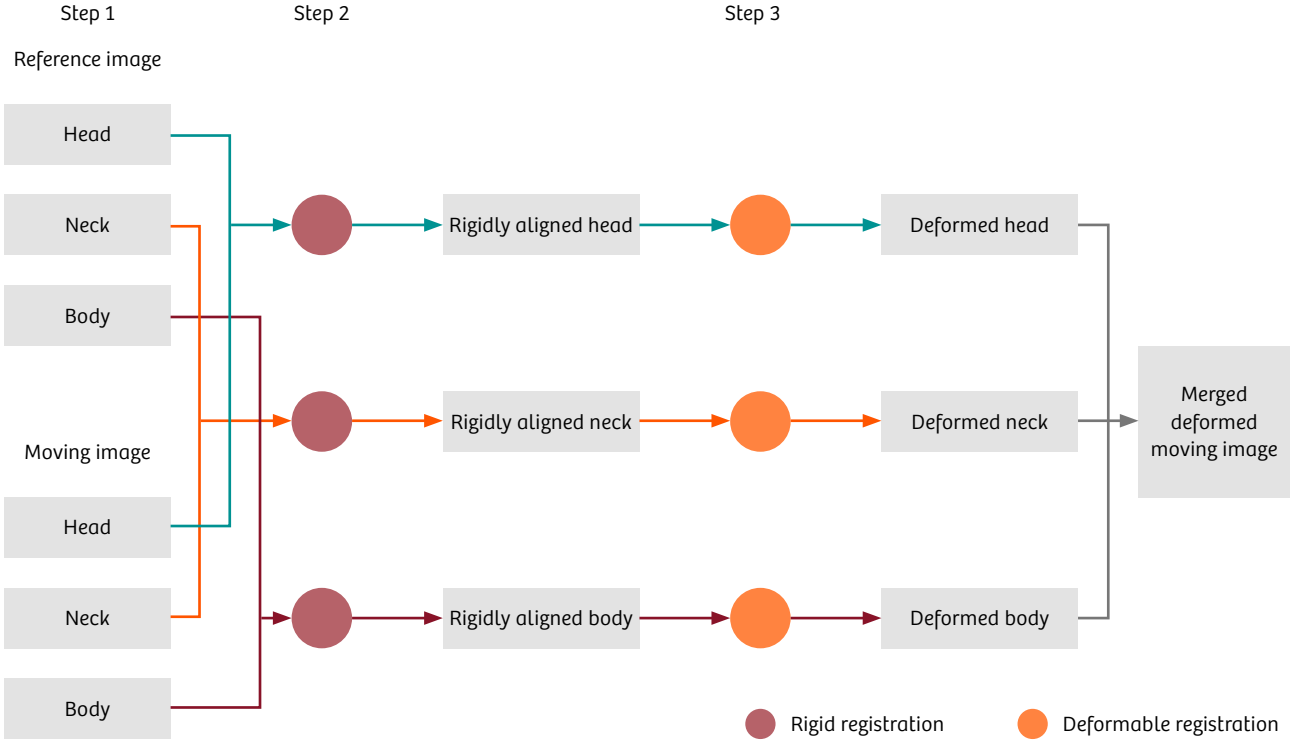


Figure 12: Deformable registration for different head-neck bending.

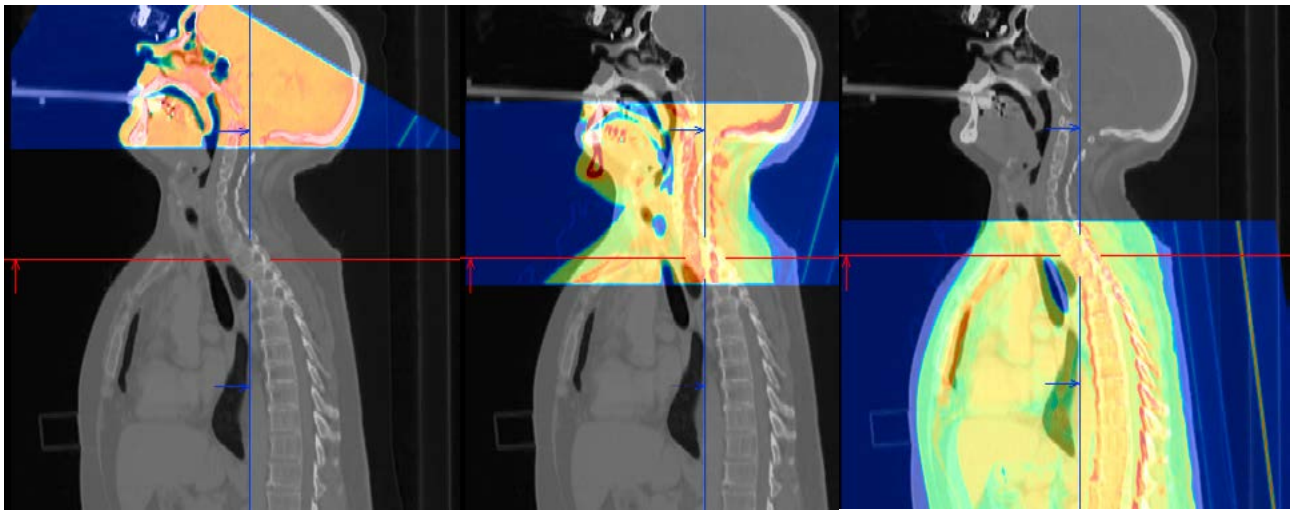

Figure 13: Fused images of the three regions after rigid registration. Gray image: treatment planning CT as the reference image; color image: diagnostic CT as the moving image.

# References

[1]: Deformable registration is optional in some configurations

[2]: Flows of diffeomorphisms for Multimodal Image Registration, C. Chefd'hotel, G. Hermosillo, O. Faugeras, Proceedings of the IEEE International Symposium on Biomedical Imaging, July 2002, Washington DC, USA.

[3]: Invention Disclosure: Li Zhang, "Region-based Registration of Head and Neck Diagnostic CT and Planning CT for Radiation Therapy", 2015E18711 US

[4]: Preliminary Patent: Li Zhang, Vladlena Gorbunova, Vincent Ordy, "Soft Tissue Specific Multi-Modality Image Fusion for Radiation Therapy", Application Number 62/066,944, Atty. Docket No. 2014P22331US

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