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Review

Registration methods in radiotherapy

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ABSTRACT

Purpose: The aim of this study is to present a short and comprehensive review of the methods of medical image registration, their conditions and applications in radiotherapy. A particular focus was placed on the methods of deformable image registration.
Methods: To structure and deepen the knowledge on medical image registration in radiotherapy, a medical literature analysis was made using the Google Scholar browser and the medical database of the PubMed library.
Results: Chronological review of image registration methods in radiotherapy based on 34 selected articles. A particular attention was given to show: (i) potential regions of the application of different methods of registration, (ii) mathematical basis of the deformable methods and (iii) the methods of quality control for the registration process.
Conclusions: The primary aim of the medical image registration process is to connect the contents of images. What we want to achieve is a complementary or extended knowledge that can be used for more precise localisation of pathogenic lesions and continuous improvement of patient treatment. Therefore, the choice of imaging mode is dependent on the type of clinical study. It is impossible to visualise all anatomical details or functional changes using a single modality machine. Therefore, fusion of various modality images is of great clinical relevance. A natural problem in analysing the fusion of medical images is geographical errors related to displacement. The registered images are performed not at the same time and, very often, at different respiratory phases.

1. Introduction

The development of computer technologies in the management of medical images achieved through diagnostic X-ray tests, computer tomography (CT), magnetic resonance (MR) or positron emission tomography (PET), has enabled those images to be compared directly on a computer screen. One of the methods for advanced comparison of medical images involves the alignment of the images followed by assessment of visible structures of the internal anatomy of patient's body. The ability to overlay images with different modalities, e.g. CT and MR, which complement the information of patient's anatomy by utilising different physical phenomena in the

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process of being generated, has considerably improved the precision of diagnostic and clinical decisions. The process of overlaying medical images is referred to as 'registration', while the effect of the registration is known as 'fusion'.

The tools for medical image registration are constantly improved. Almost every year, new technological solutions are developed (computer architecture – hardware) to shorten the time and enhance the precision of registration (mathematical algorithms used during registration – software). The accuracy of medical image fusion is very significant for a number of medical disciplines, including radiotherapy. In the case of radiotherapy, a performed and verified image fusion with the lowest geographical error enables a clear segmentation of the planning target volume (PTV) and the organs at risk (OAR) and, consequently, the creation of a treatment plan.[1–3] Registration of medical images and the evaluation of the fusion obtained is also one of the main methods to control the delivery of a treatment plan on a therapeutic machine, i.e. during patient irradiation. Irradiation during which a regular image-based control is performed is referred to as image guided radiation therapy (IGRT).[4–7]

A number of review studies have been published on image registration. But they are of a general nature and relate to various fields of science, from image theory through technical application to medical sciences. The aim of this particular study is to review the methods of medical image registration, their conditions and applications in radiotherapy. A particular focus was placed on the methods of deformable image registration.

2. Material and method

To structure and deepen the knowledge on medical image registration in radiotherapy, a medical literature analysis was made using the Google Scholar browser and the medical database of the PubMed library. The key words used in the search were *image registration in radiotherapy*, *deformable image registration in radiotherapy*, *adaptive radiotherapy*. Out of dozens of reports on medical image registration, we only selected those concerned with particular modes of registration and their use in radiotherapy. A particular attention was given to the papers describing the use of demon and B-spline deformable registration types.

2.1. *Image registration – process*

Medical image registration may be divided according to a number of factors.[8–10] Therefore, to perform the registration, some landmarks must first be identified for the input image to be aligned to the reference image. Usually, these are characteristic elements of patient's anatomy that are visible in both images, such as selected bony structures or clear-cut and distinctly visible blocks of soft tissue. Currently, there is a variety of algorithms to be used for the purpose of medical image registration.[11] The choice of an algorithm will determine the method and type of transformation the input image will undergo when being registered with the reference. The final and the key part of the whole process is the evaluation of the fusion received. The evaluation should take into account both the algorithm-specific quantitative parameters and the qualitative parameters that specify diagnostic utility of the registration or, in other words, assess if the registration has delivered some added information on patient's anatomy as compared to that provided by the reference image alone.

2.2. *Chronological review of image registration methods in radiotherapy*

The first medical image registration methods implemented in computer programmes and used in radiotherapy were those based on simple and complex rigid transformation algorithms. They rely on mathematical transformations, such as rotation and translation along each axis of the Cartesian coordinate system, as well as scaling and shearing of an image projected onto a reference.[12–14] Simple rigid registration uses the first two of the above transformations, while complex rigid transformation also involves scaling and shearing. Fig. 1 shows a schematic of the basic transformations used in rigid image registration methods.

In rigid registration, transformations are performed in a 3D space and images are matched according to the properties of pixels or voxels or by alignment of contours associated with selected anatomical structures as shown in the images. Rigid registration is global in nature, meaning that particular parts of the input image are not able to be deformed in relation to one another, and the fusion obtained is a superposition between the input and reference image. Superposition of images is, in turn, conditioned upon the underlying registration parameters (points, surfaces or mapping volumes that are identical and clearly specified in both images being compared).[14,15]

Rigid registration is an indispensable tool in patient positioning before the delivery of fractional dose. In that case, rigid registration of CT images that formed the basis for treatment plan with CT images (e.g. cone beam computed tomography – CBCT) allows to determine the values by which the therapeutic table with the patient on it should be moved so that the current patient's position reflects as far as possible the position taken while the CT images used in treatment plan were being made.

Unfortunately, the rigid registration methods may not be reliable in determining the target volume and organs at risk in the course of treatment planning. Registering MR or PET images with reference CT images should provide measurable benefits of added information on patient's anatomy. However, the global nature of rigid registrations often leads to unacceptable discrepancies between the positions of particular anatomical structures in images being compared. The discrepancies arise from the fact that images can be taken at different times or for different body positions.

In the assessment of anatomical changes that occur in the patient's body during radiation therapy, rigid registration methods enable a qualitative visualisation of discrepancies between reference CT images (treatment planning, images generated before the onset of therapy) and the input CBCT images generated during radiotherapy. Nevertheless, rigid transformation parameters (rotation, shift, scaling) do not make it possible to quantify those changes. Nor is it possible, based on those parameters, to map and deform the