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Software for the Use of Multi-Modality images in External Radiotherapy

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1. Introduction

This report presents the assessed workflow in radiotherapy. It is one of the deliverables of the SUMMER project. Understanding of the radiotherapy workflow is needed in order to design new software and new User Interfaces (UI) for system computer interactions that fit into the clinical context. Understanding the workflow is especially important since there also different between institutions and countries.

Furthermore, understanding the workflow gives the multi-disciplinary team members in the consortium a basis to be able to work together. They all need to understand what is happening in the medical work. Furthermore it is important to understand the same vocabularies in the same way to collaborate more effectively.

In this report an overview will be given of what is a workflow , roles of different people in the radiotherapy work. The entire radiotherapy workflow will be presented in flowcharts. A more detailed workflow analysis will be presented about those phases in the radiotherapy process that are in the focus of SUMMER, especially 'contouring'. In design, in iterative rounds the workflow needs to be inspected, gradually moving to goal and task analysis even to the level of cognitive micro steps (Cuijpers, Moelker, Varga, Stappers, & Freudenthal, 2012). Eventually the workflow will change for the better, and a new workflow will be proposed together with the new design. Whether the changes in workflow will be big or small are yet to be seen.

Because of developing technologies and medical practice, workflow cannot be seen as static.. More thorough analysis of new approaches of radiotherapy (e.g., adaptive radiotherapy, dose painting and protontherapy) and limitations of the current workflow are described by Aselmaa et al. (Aselmaa, Goossens, Laprie, et al., 2013) Design should actually anticipate or facilitate these expected trends as well.

2. Preface

This document describes how are things happening now in the clinical setting. This is based on the observations carried out in Institut Claudius Regaud (Toulouse, Fance) and in Universitätsklinikum Freiburg (Freiburg, Germany).

Radiotherapy (radiation therapy) can be external (the radiation source is external to the patient's body) and internal. External beam radiotherapy uses high-energy radiation to kill cancer cells. It is often an effective way to kill cancer cells that cannot be removed during surgery ("Radiation Therapy for Cancer," 2013). Internal radiotherapy, commonly called brachytherapy, places the radioactive material into the body in the proximity of the tumorous cells.

2.1 Vocabulary

Table 1 Vocabulary

Term	Definition within this document
Workflow	Collection of linked tasks, resources and information elements which are involved in specific process to achieve a specific goal
Treatment	Refers to external radiotherapy treatment unless specified otherwise
Image co-registration	The step preceding image fusion where the different sets of data are transformed into one coordinate system. The result of co-registration aims to gather information specific to several image modalities, that put together will bring relevant/new information
Image fusion	The action where 2 different images are "merged" into one. NB! In medical usage the "image fusion" is used as a synonym to "image co-registration"
Dosimetry	The process of planning the dose distribution for radiotherapy treatment.
RT	Abbreviation for radiotherapy, within this document refers to external radiotherapy.
Contouring	The process of identifying regions of interest (tumor or organs) by drawing a

	line on the border of the region of interest. Also referred to as 'delineation' or 'segmentation'. 'Segmentation' typically refers to algorithm-based contouring with no or limited user involvement.

2.2 Workflow definition

Workflow can be defined as "the automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules" (Hollingsworth, 1995) or more loosely "the specific collection of tasks, resources and information elements involved in […] a circumstance comprise a workflow" (Basu & Blanning, 2000). It can be even viewed that each alternative within a workflow creates a new workflow or that each sub-process can be a stand-alone workflow.

Within this document, workflow is defined as "collection of linked tasks, resources and information elements which are involved in specific process to achieve a specific goal".

2.3 Different workflows in radiation oncology

In a radiation oncology department there are multiple workflows happening in parallel. They influence each other one way or another – failure or delay in one workflow (i.e., quality assurance (QA) of a treatment machine has not be finished on time) influences other (i.e., patient treatment has to be done on a different machine or rescheduled).

Table 2 Different workflows in radiation oncology

Workflow	Examples
Administrative workflows	Scheduling patients; Ordering supplies
Machine QA workflows	Installing new machine; Daily QA; Weekly QA
Patient treatment workflows in external RT	Curative treatment or Palliative treatment
Clinical trial workflow	Trial specific

The focus of this document is a general radiotherapy workflow of one patient.

2.4 Participants

The process of creating and executing the external radiotherapy treatment plan spread over a long period of time and involves many participants. It is important to mention that there are international differences between the names of the professions and the tasks they are responsible for.

Table 3 The overview of (main) participants in external radiotherapy

Participant	Definition
Patient	The person with cancer
Patient's family	The supporting people who are accompanying the patient
Physician	A person with medical degree
Radiologist	A physician who is specialized in the interpretation and reading medical imaging
Technician/ Radiotherapy Technologist	A person who is skilled in using medical technology. In Radiotherapy the technicians are sometimes called as Technologist. They receive specific specialization for the different treatment machines/accelerators
Radiation oncologist	A physician who is specialized in radiotherapy
Medical resident	A graduated medical student, who is in training in clinical setting
Medical oncologist	A physician who is specialized on medication based cancer treatment

Nuclear medicine physician	A physician, who diagnoses and treats diseases using radioactive materials and techniques. Also involved in PET image acquisition.
Surgeon	A physician who is qualified to perform surgery. The surgeons specialized in oncology are called as Surgical Oncologist
Medical physicist	A person who has finished a special training on medical physics
Dosimetrist	A person who is specialized in RT planning (from patient file management to images fusion and dose plan computation)

2.5 Possible data within RT

- Imaging data
  - Diagnosis IMG*
  - Pre-operative IMG*
  - Immediate post-operative IMG*
  - RT planning IMG*
  - Follow-up IMG*
- Patient data
- Radiologist reports
- Surgeon's report
- Anatomopathological report
- Patient's history report
- Treatment protocols
- Clinical trial protocol
- Other clinical trial documents
- Delineation rules/guidelines
- ...

IMG* = CT, MRI*, PET or PET-CT

MRI* = MRI T1-weighted pre-contrast (before the injection of contrast agent), MRI T1-weighted post-contrast (after the injection of contrast agent), MRI T2-weighted, MRI FLAIR, MRI Diffusion, MRI Perfusion, MRI Spectroscopy (mono-voxel, multi-voxel), fMRI.

2.5.1 Data carrier means

There are many potential data carrier means.

- Paper
  - Patient folder
  - Other forms
  - Fax (clinical trial, reports from other hospital)
- Digitization of paper documents into the electronic patient folder
  - Scans of medical reports from different departments (surgery, anatomopathology, biology...)
- CD
  - Imaging from other hospital
- Online systems: data exchange
  - PACS (Picture Archiving and Communication System) and all the software solutions
  - E-mail
- International Commission/Quantitative Analysis reports/Reference Protocols/Multi-disciplinary meeting
  - The knowledge (from previous experience)
- People/colleagues
  - The knowledge

3. Radiotherapy workflow of one patient

The current patient workflow from external radiotherapy point of view can be summarized in the following (not strictly linear) steps:

1. Diagnosis
2. Multi-disciplinary meeting
3. External radiotherapy patient consultancy
4. Planning preparation
5. Image fusion
6. Contouring
7. Dose prescription
8. Dosimetry
9. Treatment
10. Validating treatment position images
11. Per-treatment follow-up
12. Post-treatment follow-up

Cancer treatment is often not only external radiotherapy. Before, during or after the external radiotherapy, there might be chemotherapy, surgery or some other treatment. For instance, commonly for cranial tumors, radiotherapy treatment is recommended to start some weeks after surgery. These other treatments may influence the general workflow of external radiotherapy or change information needs for decision making during radiotherapy treatment planning. To mention few influences:

- In case there has been surgery, additional pre-operative images will be needed.
- In case of chemotherapy, pre-chemo images might need to be taken into consideration.

Once the patient has been diagnosed and the treatment plan possibilities have been discussed in a multi-disciplinary meeting, and external radiotherapy has been decided upon as part of treatment plan, the patient comes to the radiotherapy consultancy. During the consultancy, the process of radiotherapy and the steps involved in it are explained and planned.

The next step is to gather all needed data. For all cases a planning CT scan is done, but there may also be other procedures as well (immobilization system, gating training...). Once all information about the patient and the tumor has been gathered, the planning of the treatment can start.

If needed, images are combined in order to get information in a combined way. Next, the target volumes with the margins around the tumor and the organs at risk are contoured on the images. The planned doses and limitations of doses for the tumor and the organs are defined.

The last step before starting the treatment on the patient is to create and validate a dose plan that is covering the tumor as prescribed and sparing the organs at risk as limited.

Now the treatment can start. Treatment is delivered in several fractions over 5-6 weeks unless it is a palliative radiotherapy case. But there can also be hyperfractionated treatments (the total dose of radiation is divided into small doses and treatments are given more than once a day) as well as hypofractionated treatments (the total dose of radiation is divided into large doses and treatment is delivered in few fractions over few days). Majority of the times, the treatment plan made prior to the first fraction is used for all the fractions.

Depending on the type of treatment, the treatment position is validated by an oncologist in order to ensure that there is no or limited deviation from the planning position.

Also there are weekly follow-up meetings during treatment to evaluate treatment tolerance and immediate secondary effects. Sometime after the complete treatment there will be post-treatment follow-up meetings to evaluate the success of the treatment.

3.1. Diagnosis

The starting point usually is that the patient is having some health complaints and reaches the corresponding doctor. In case of lung problems (difficulties to breath, coughing, etc.), the doctor would be a pulmonologist. In case problems in the head (headache, dizziness, other neurological problems), the doctor would be a neurologist.

The doctor will conduct series of tests/medical procedures in order to determine what might be the cause for the symptoms. Diagnosis is not always straightforward process and missed or delayed diagnoses of cancer may occur. For instance negative mammogram may lead to missing breast cancer until the patient returns.

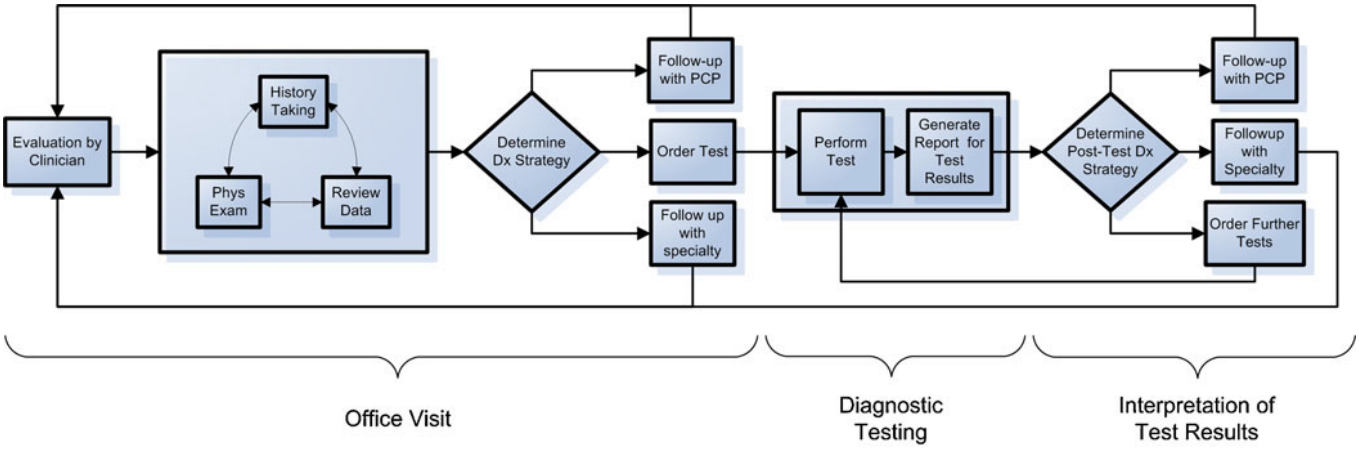

Figure 1. Clinical activity flowchart of breast and colorectal cancers: clinical activities associated with the diagnostic process (Poon, Kachalia, Puopolo, Gandhi, & Studdert, 2012) *PCP* **=** *Primary Care Physician*; *Dx* **=** *Diagnostic*

If a patient is diagnosed as having cancer then the doctor refers the patient to the specialized physicians for the treatment of his cancer (e.g., surgeon, oncologist).

Patient is sent to a Cancer Treatment Center after the diagnosis of cancer has been established and after surgery if the tumor resection is possible. This means that from radiotherapy workflow point of view the sources of information come from different departments/institutions. This in turn means that there may be difficulties in acquiring all the information about the patient that was gathered previously (during diagnosis, pre-/post-operatively).

3.2. Multi-disciplinary meeting

Multi-disciplinary meeting is a review meeting where all (new) patients are discussed and optimal treatment plan is discussed and decided upon. Different physicians, such as radiation oncologist, medical oncologist, surgeon and the organ specific physician are participating in it. The outcome of the meeting should be an optimal treatment care for the patient (surgery if possible, radiotherapy associated with chemotherapy or not, etc.). Not all patients discussed here will have external radiotherapy.

The frequency of these meetings is dependent of the country. For instance in France the multi-disciplinary meeting is roughly once a week. Duration of a meeting is 1-1,5h and one patient is discussed from few minutes to 15 minutes depending on the complexity of the case.

Another difference between countries is which type of patients are discussed – all new patients or only complicated cases.

3.3. External radiotherapy patient consultancy

During the radiotherapy patient consultancy radiotherapy treatment is discussed and details are decided upon.

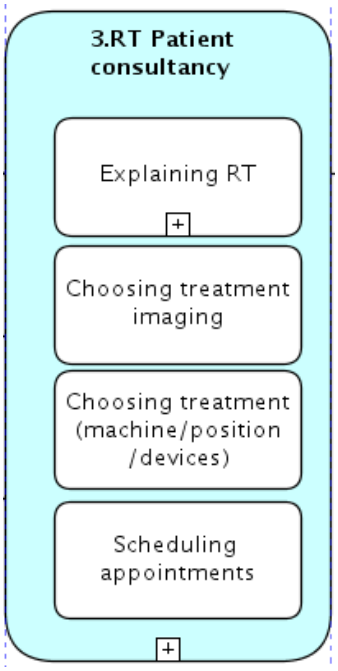

Figure 2. RT Patient consultancy

This is the time when the patient (and patient's family) meets with radiation oncologist. The treatment is explained and questions are answered.

The radiation oncologist has to decide during the meeting what will be the treatment machine, position and what type of custom accessories are needed for patient positioning.

Furthermore the patient is scheduled for the next appointments, such as:

- CT acquisition,
- MRI acquisition
- PET acquisition
- Blood tests
- etc.

After the diagnosis, the patient might have had meetings with other physicians in case the patient has had other type of treatment (chemo, surgery, etc.) also.

3.4. Planning preparation

The aim of the step "planning preparation" is to gather all relevant information about and from the patient.

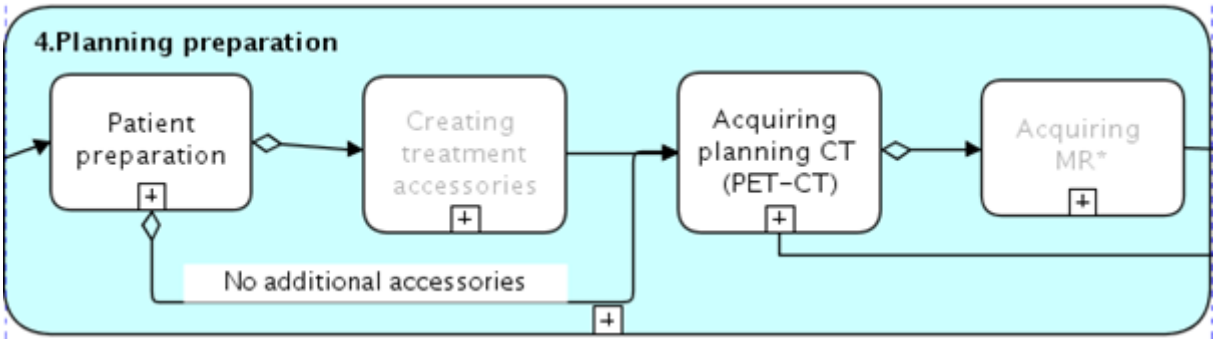

Figure 3. Main tasks in planning preparation process

The steps shown in Figure 3 are not always happening in parallel. For instance quite often the "patient preparation" is happening immediately prior to the "acquiring planning CT", while the "creating treatment accessories" can happen after the CT acquisition.

For all the patients there will be tasks of "patient preparation" and "acquiring planning CT" (but not PET-CT). Optionally for some cases there might be also need to create treatment accessories and/or acquire MR images.

3.4.1 Patient preparation

The aim of the task "patient preparation" is to prepare everything needed for image acquisition and patient re-positioning later during each fraction delivery. The main tasks are mentioned is Table 4.

Table 4 Subtasks of the task "Patient preparation"

4.1.1 "Alter" the patient	Make changes in the patient that would support the later parts of the process
4.1.2 Define patient treatment position	Create and/or define patient positioning devices to be able to reproduce patient's position for each treatment session

4.1.3 Gather patient's files	Ensure all relevant already existing information is available

3.4.1.1 "Alter" the patient

The aim of this task is to prepare the patient for image acquisitions by specific procedures.

For all patients, small tattoos (usually called as BB points or Planning points) are made on the skin. These points will be used during treatment delivery in order to re-positioning patient for each treatment session into the same position as during the planning CT acquisition.

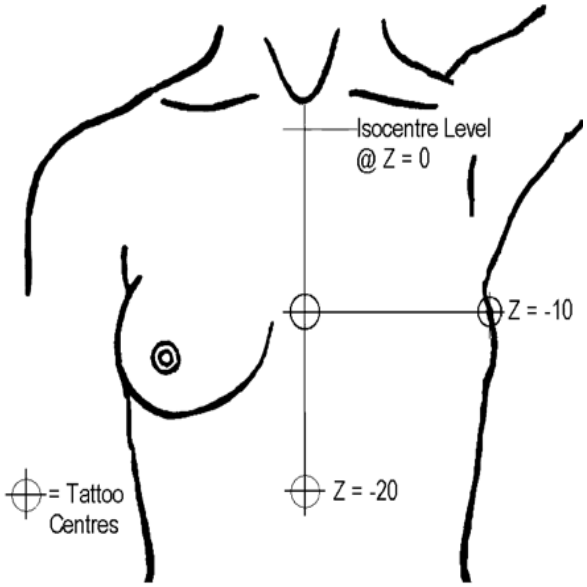

Figure 4. Isocentre and tattoo centres (Truong et al., 2005)

Depending on the cancer type, the patient might undergo specific procedures. For example, for prostate cancer it may mean that a special procedure is done to implant fiducial gold markers into the prostate. Prostate is known to move a lot between and even during the treatment execution time (Dehnad et al., 2003). Also the prostate is not too well visible on imaging. Therefore the gold markers are useful since they are well visible on images and based on them, the patient's position can be reproduced better during each treatment time.

3.4.1.2 Define patient treatment position

The aim of this task is to create the patient positioning devices and/or define the position of them. The specific devices depend on the cancer type. For instance, for head or head and neck cases a thermoplastic mask may be created. Depending on the institution it might be created during the CT acquisition time-slot (e.g., if there is a dedicated machine for radiotherapy) or it might be created prior to the CT acquisition, but on the same day (UK).

3.4.1.3 Gather patient's files

The aim of this task is to ensure that all relevant data from the patient history is available. Patients are not typically diagnosed in the same hospital, or even if they are it's not from the same department, there is some level on administrative tasks in gathering all the data of the patient. For instance pre-operative and post-operative images of patient may exist, but they need to be added to the local system also.

3.4.2 Creating treatment accessories

In some cases special equipment is needed for the treatment.

For instance, for tumors which are close to skin, electrons may be used for the treatment instead of photons. To treat with electrons the an electron applicator will be attached to the head of the treatment machine.

Technician/radiotherapy technologist then have to place an insert into the end of this applicator that is specific to the exact shape and size required for each patient's treatment. ("Electrons," 11/10/2010)

Figure 5. Electron applications

3.4.3 Acquire planning CT (PET-CT)

For all patients the CT is acquired, this is a technological requirement to support the dose calculation for the linear accelerators. For some cases however, the CT is acquired together with PET, which results in a fused PET-CT which is also suitable for dosimetric purposes.

It may happen that the PET is acquired independently from CT, that means that the patient's position is different during the acquisition of CT and PET which will in turn require a co-registration step before contouring.

3.4.4 Acquire MR images

Sometimes there are MRI images acquired (e.g., brain tumor cases). MRI acquisition consists of a sequence of acquisitions – T1-weighted MRI before and after injection of contrast enhancing product, T2-weighted, FLAIR (Fluid Attenuated Inversion Recovery), etc. This list may be even longer in case of a clinical trial – for example acquisition of MR Spectroscopy Imaging (MRSI) or functional MRI (fMRI). The acquisition of one sequences of MRI takes from 3 to 10 minutes, one full appointment can take up to 1h per patient.

3.5. Image fusion

(NB! "fusion", "registration, "co-registration" are often used as synonyms in medical context.)

Image fusion is needed in the situation when CT itself is not sufficient for identifying the location of the tumor.

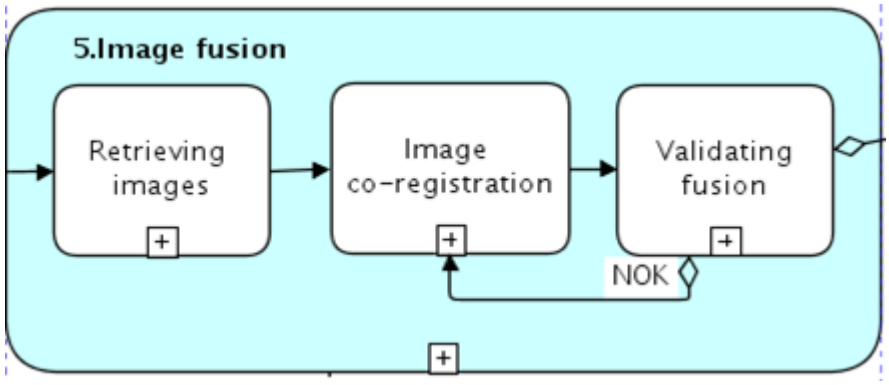

Figure 6. Main tasks in image fusion process

During patient consultancy the radiation oncologist decided on which imaging modalities are needed/available. In order to use the information from each of the relevant image set, they need to

be combined in a good way. There are two types of fusion: intra-modality fusion and inter-modality fusion.

The goal of "image fusion" process is to combine and link information from different image sets to allow better comprehension and support the decision making on the location of the tumor(s) and organs at risk. As the planning CT is always needed for dose calculation, typically the fusion is made with the planning CT as the reference data set.

3.5.1 Retrieve images

The aim of this step is to make the images that need to be fused available in the system/software. When requests among PACS from different institutions/cities are possible, the images are conciliated into the local patient folder. Otherwise, CDs can be sent.

For specific clinical trial like "SPECTRO-GLIO" ("Phase III Study Comparing 2 Brain Conformational Radiotherapy in Combination With Chemotherapy in the Treatment of Glioblastoma (SPECTRO GLIO)," 2013), an on-line database was built for a rapid exchange of imaging and radiotherapy treatment data and on-line quality control (only limited access was authorized to specific people of the different centers participating to the trial).

3.5.2 Co-register images

The aim of this step is to spatially align different image data sets. The co-registration may be performed for the same modality of images (e.g., two T1-weighted MRI acquired on the same patient but at different time = "intra-modality" co-registration) or different modalities of images (e.g., T1-weighted MRI image set can be co-registered to CT scans = "inter-modality" co-registration). The result of the co-registration is a mathematical transformation defined by the "registration matrix". Depending on the software there is possibility for automatic, manual or semi-automatic co-registration. The exact steps depend on specific software.

The co-registration can be relatively slow process. One of the biggest challenges of co-registration is that most of the times modifications occurred between the two image sets acquisition, e.g., the position in which the image has been acquired might have been different, there might have been post-surgical tissue re-organization etc. This produces challenges for the users to decide in which region of interest the co-registration has to be optimal and in which area a shift can be tolerated.

The co-registered images are then evaluated by changing the opacity level and visually evaluating the alignment of some anatomical points (considered as landmarks). Checking needs to be done in the three orthogonal planes. Axial plane is typically the starting point. Once the images are well co-registered on axial plane, the coronal and sagittal ones will also be checked.

3.5.3 Validate fusion

The aim of this step is to decide whether the images are correctly co-registered. Validation of fusion is happening iteratively with co-registering images. If the images are not well enough co-registered, then there will be changes made and another validation.

Quite often the final fusion is not done by a senior physician. Therefore the fusion has to be approved by a senior physician to be sure that the images are correctly co-registered. If for any reason the images are incorrectly fused but still approved, it would mean that the contours will be “translated” to the CT with a spatial shift/error, meaning the spatially incorrectly defined target volume will then be irradiated.

3.6. Contouring

The assumption for this step is that the correct patient data has been loaded into the system.

Contouring process can be simplified into the following (not necessarily linear) steps:

1. Delineating the body
2. Delineating organs at risk (OARs)
3. Delineating gross tumor volume (GTV) --> macroscopic disease
4. Delineating clinical target volume (CTV) --> microscopic disease, i.e. infiltration
5. Delineating internal target volume (ITV)--> the expected movement area of CTV during treatment. ITV is drawn only for very few cases (e.g., in lung)
6. Delineating planned target volume (PTV) --> defined by setting some margin to take into account treatment positioning errors

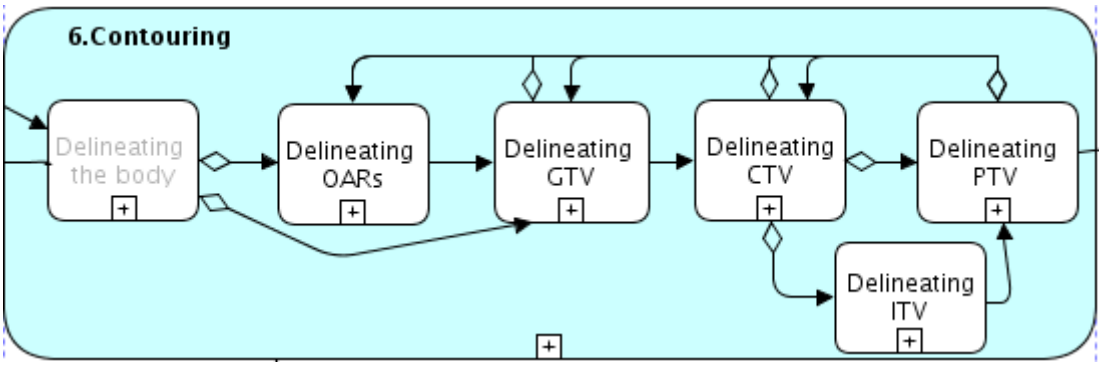

Figure 7. Main tasks in contouring process

The order of the above mentioned steps is typically in this order, but it is not limited to it. For instance the CTV can be contoured before organs at risk. Though GTV->CTV->PTV are dependent on each other, meaning first must be GTV, then CTV and last PTV. Furthermore for some types of tumors physicians delineate directly CTV without a GTV (e.g., head and neck case) or there is no CTV and only a PTV. Adjustments to contours can be done at any given point – meaning while delineating CTV, adjustment to the contour of an OAR might be made.

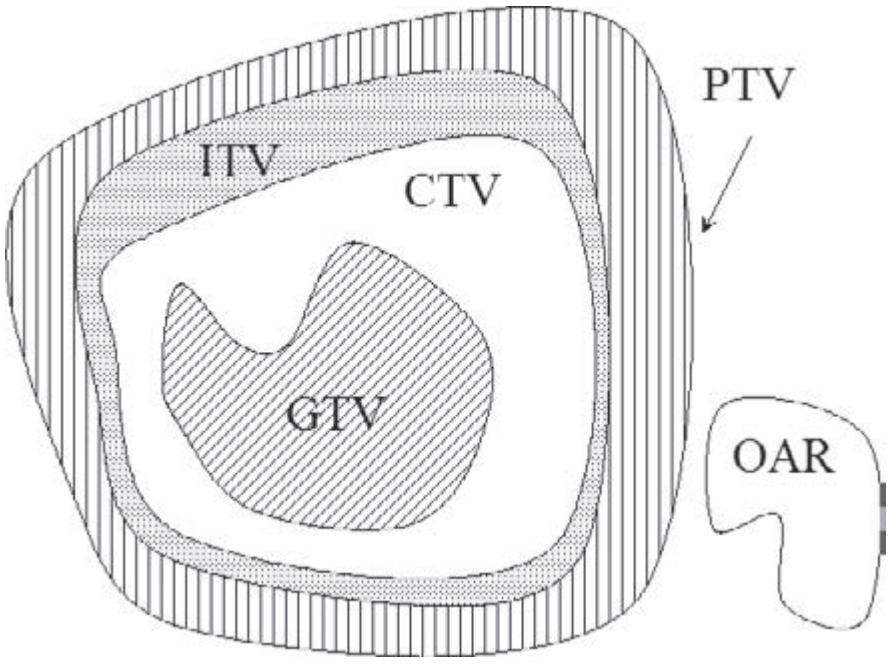

Figure 8. Graphical representation of the target volumes, as defined in ICRU Reports No. 50 and 62 (Parker & Patrocinio, 2003).

The general underlying process for any user-dependent contouring is shown on Figure 9. The core process of slice based contouring. A contouring task consists of three main activities “Identify modality”, “Identify slice” and “Delineate”, and two main decision making point for the questions “Are contours good on this slice?” and “Are there more slices to consider?”.

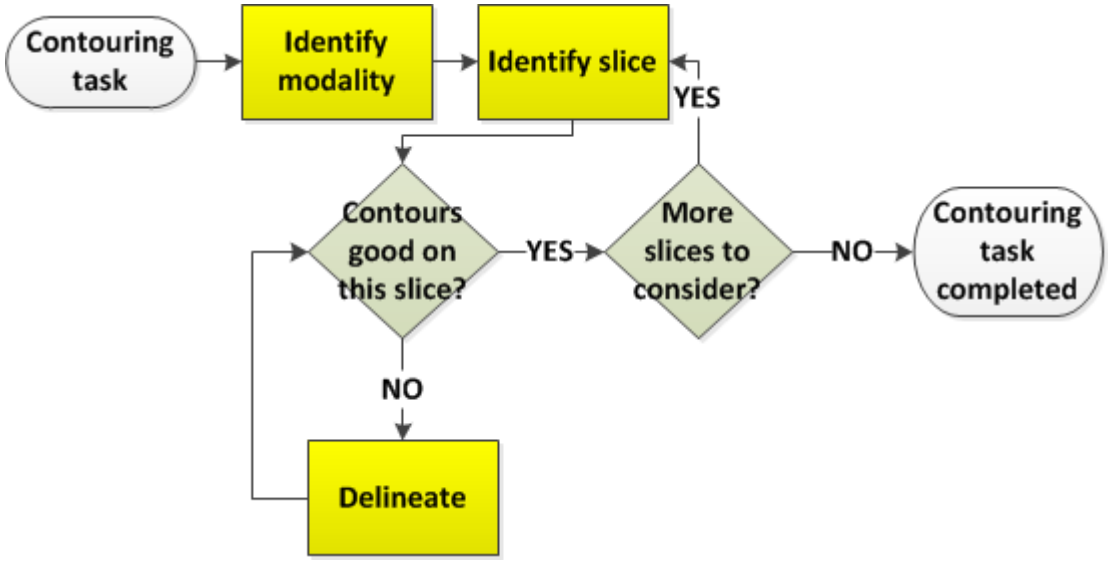

Figure 9. The core process of slice based contouring

Each of the tasks and decision making points consists of cognitive and physical tasks Table 5.

Table 5 Main cognitive and physical tasks of the core process

Step in the process	Cognitive tasks	Physical tasks
Identify slice	• Decide whether having enough anatomical and medical knowledge. • Compare neighbor slices to decide if the current slice is relevant.	Switch/Scroll through image modality and slice set.
Decision: Are contours good on this slice?	• Are there any contours on this slice? • Compare contours with neighbor slices. • Decide whether the contour captures the full object being contoured. • Compare contours on different modalities.	Manipulate the view of the slice (scroll, zoom, move). Open additional views.
Delineate	• Decide where to contour	Contour with the mouse or new tools (basic contouring tools are pencil with adjustable diameter, static or 3D pencil, magic brush…) + Basic object manipulation (Boolean operation, enlargement, reduction, ring definitions)
Decision: More slice to consider?	• Is the object visible on the selected slice? • Compare with neighbor slices.	Manipulating the view (zoom, move). Switch/Scroll through image modality and slice set.

In the task of defining target volumes within the context of external radiotherapy treatment planning, the key cognitive processes which need support are problem solving (consisting of information foraging and sensemaking loops) as well as decision making. As part of this view, sensemaking of target volumes can be described as interpreting the medical images and textual reports based on the mental images and models; hypothesis generation of the target volume border location; and evidence finding to evaluate the hypothesis (Aselmaa, Goossens, & Freudenthal, 2013).

3.6.1 Delineating the body

Delineating the body is mandatory for some TPS since the SSD (Source Skin Dose) is needed to compute the dose inside the volume. Nowadays it is typically done automatically by the software.

In addition, the body structure is used to create new structures like PTV-body in order to crop the part of PTV that is outside the body to avoid air being part of PTV.

3.6.2 Delineating organs at risk (OARs)

While delivering the optimal dose to the tumor volumes, external radiotherapy aims to spare healthy tissue. This is done by following two principles – avoiding irradiating unnecessary tissues/organs and reducing the toxicity as much as possible.

Through experience and research, supported by the relatively fast evolution of radiation techniques, quantitative analyses are performed to define recommendations for dose tolerance to organs, these recommendations are regularly updated (QUANTEC - Quantitative Analyses of Normal Tissue Effects in the Clinic). Dose limit is defined per organ and is describes as a dose limit for which the organ still preserves its function. There are two types of organs – parallel and serial (analogy to the electricity domain can be made). For a parallel organ, the mean dose for the whole organ matters. For a serial organ, the maximum in any location within the organs matters. This knowledge is important for dosimetry planning.

Table 6 Subtasks of a task "Delineating OARs"

Task	Goal of the task
6.2.1 Identify list of OARs	To know what needs to be contoured according to tumor location
6.2.2 Delineate an OAR	Identify the location of the OAR in the image datasets/modalities
6.2.3 Validate delineations	Validate that the OAR has been properly captured on the image dataset

The delineation process is not always as straightforward as shown in Table 6. Depending on the expertise level, external knowledge may be needed. For instance a delineation handbook, guidelines or automatic atlas segmentation of OARs integrated in contouring software solutions might be used. Also discussions with colleagues are not uncommon.

3.6.2.1 Identify list of OARs

The first step, as part of delineating OARs, typically is to define (or load pre-existing) list of OARs into the system (they are called templates) – from the location of the tumor it is known what are different organs in the proximity. Quite often this list is adjusted – some organs are removed (for instance the tumor is location-wise very far and it is known that there will not be critical amount of dose in that area), or some organs added. With the newer techniques (such as TomoTherapy), it has become more important to delineate all organs at risk. This is because the software automatically optimizes the dose plan and as a consequence may give unnecessary dose to the OARs if priorities are not properly set.

3.6.2.2 Delineate an OAR

Each of the organ at risk needs to be delineated. There have been technological advancements which allow automatic or semi-automatic delineation for some organs. Also for some organs at risk the existing tools are supporting well the contouring. For instance, in Eclipse ((Varian Medical Systems, Palo Alto, CA) there is a possibility to draw a 3D ball which is good for delineating the eyeballs quickly.

Most of the cases though, the automatic or semi-automatic delineation is not good enough, and some manual corrections are needed after an automatic segmentation. Unfortunately, if the number of manual adjustments is too high, physicians prefer to do the whole contouring manually. Therefore, the typical process of delineation still has remained manual slice-by-slice mainly on the orthogonal planes supported by interpolation technique. Depending on the location of the tumor and

the size of it, the list of OARs can become rather long. For instance for a brain tumor, the list of OARs that could be following:

- Spinal Cord
- Brainstem
- Chiasm
- Optic nerve ipsilateral
- Optic nerve controlateral
- Eyes
- Lens
- Inner ears
- Hippocampus
- Healthy brain - PTV

The images of the patient are typically viewed in axial slices, or at least the final evaluation of the contours is done on the axial slice. This slice based approach to delineation can become extremely time consuming. A CT scan can be acquired in 1millimeter slice thickness. Roughly this means for 1 centimeter of organ contours on 10 slices are needed. In case there is no software support for semi-automatic or automatic contouring, the user has to go through each of the slice manually. Continuing with an example of 1cm OAR, the core process depicted on Figure 9 would be then iterated at least 10 times.

The software vendors have been working on reducing the time needed for delineation and one of the known functionality is interpolation. The interpolation functionality allows the user to contour on fewer slices. The contours on in-between slices will be interpolated according to the contours of the "edge" slices.

Semi-automatic and automatic delineation of OARs exists to some extent. Unfortunately though, most of the time the effort needed to adjust the automatic contours is not significantly less than fully manual (slice-by-slice) contouring.

3.6.2.3 Validate delineations

Quite commonly a resident or junior physician does the delineation of OARs in order to gain more experience. Also since it is a time-consuming task, senior radiation oncologist might not have time for it next to all the other daily responsibilities. Once the contours of OARs have been finalized, a senior radiation oncologist has to validate them. Sometimes this also means that the contours will be adjusted for some OARs, if the senior physician does not fully agree with the previously done contours.

3.6.3 Delineate tumors (GTV)

This step is the core of the overall contouring process. At the same time this is also the most difficult one. Gross tumor volume represents the "macroscopic visible" part of the tumor. The "visible" is in quotations because on the images, expansion of tumors is not always that clear as a border line. There is rather high level of uncertainty about where goes the border of the "visible" tumor. Several studies have shown that different physician contour the "visible" border of tumors differently (Weiss & Hess, 2003).

Table 7 Subtasks of the task "Delineate tumors (GTV)"

Task	Goal
6.3.1 Retrieve patient information	Get everything needed for understanding the tumor's location /surgery outcome.
6.3.2 Build understanding of tumor(s)'s location	Know where to contour tumor macroscopic expansion
6.3.3 Delineate tumor	Capture the tumor's location on the images
6.3.4 Validate contours	Confirm the location contoured is the appropriate

3.6.3.1 Retrieve patient information

The common actions for this step might be as simple getting the patient's paper folder and/or opening the patient in the treatment planning system. In more complicated cases it might mean that more information is needed from a different institution. For example if the PET images are not acquired in the same institution – there might be a need to make extra effort to retrieve the images fast.

As a result of this step the patient information has been loaded to the treatment planning system – the software solution that is used to do the actual contouring.

3.6.3.2 Build understanding of tumor's location

The doctor sits down in front of the computer. She scrolls trough the images, paying more attention to some slices, less to other. She builds rapidly an understanding of the overall situation (3D body) and is now ready to start delineating.

Since the tumor can be anywhere, it takes some effort to understand where is the tumor. The understanding is built upon past experience and anatomical knowledge (internal knowledge) but also by reading report of the patient and other relevant documents (external information).

Table 8 Subtasks of the task "Build understanding of tumor's location"

Task	Goal
6.3.2.1 Reading reports of the patient	Attain the clinical picture
6.3.2.1.1 Reading patient's history report	Know the disease history
6.3.2.1.2 Reading anatomopathological report	Know the description of tumor cells (what type of tumor, how it looked, microscopic spread of tumor etc.)
6.3.2.1.3 Reading surgeon's report	Know what was done with the tumor during surgery (partial/complete removal etc.)
6.3.2.2 Viewing images of the patient	"See" the tumor in the images
6.3.2.3 Reading treatment related document	Know how the tumor should be contoured

The initial understanding of the tumor is built from reading and viewing, but the understanding deepens throughout the delineation process, while the contours are drawn and adjusted. However for complex cases, external support is needed to understand the tumor better and for example radiologists may be consulted.

3.6.3.3 Delineate tumor

Once the physician has decided where is the tumor (meaning decided where are the "visible" borders of the tumor) the action itself, contouring the border, on the selected slice selected starts.

This process is following the core delineation process depicted on Figure 9.

3.6.4 Delineate clinical target volume (CTV)

The medical purpose of CTV (clinical target volume) is to capture the microscopic spread of the tumor cells which is confirmed by previous histology studies, but cannot be seen on the images (as it is microscopic). Typically it is defined as a margin from the GTV (e.g., for a brain tumor, CTV can be the enlarged GTV by 17mm).

Table 9 Subtasks of the task "delineate clinical target colume (CTV)"

Task	Goal
6.4.1 Generate initial contours	Include medical knowledge of microscopic spread
6.4.2 Adjust contours	Correct contours where it is known medically that the tumor will not be present
6.4.3 Gather relevant information	Get addition external knowledge
6.4.4 Evaluate the contours	Decide whether the contours are good

3.6.5 Delineate planned target volume (PTV)

The medical purpose of PTV (planned target volume) is to capture the possible movement of the organs, patient and treatment table (setup errors and margins) to be sure that even with those movements the tumor will be properly irradiated. This is done by adding a margin to CTV.

Table 10 Subtasks of the tasks "delineate planned target volume (PTV)"

Task	Goal
6.4.1 Generate initial contours	Include medical knowledge of microscopic spread into the work in an easy way
6.4.2 Adjust contours	Correct contours where it is known medically that the tumor will not be present
6.4.3 Gather relevant information	Get addition external knowledge
6.4.4 Evaluate the contours	Decide whether the contours are good

3.7 Contouring tools

Different existing tools support different ways of contouring. The common tools are:

- Pencil (also called brush) with adjustable diameter;
- static or 3D pencil;
- smart brush (threshold based selection);
- interpolation (automatically creating the contour based on other contours on different slices);
- “Nudging” based contour adjustments (e.g., Pearl tool in Oncentra Masterplan)

3.7. Dose prescription

Once the contours are defined, the exact doses for the target volumes and limitations for the organs at risk need to be defined (Figure 10).

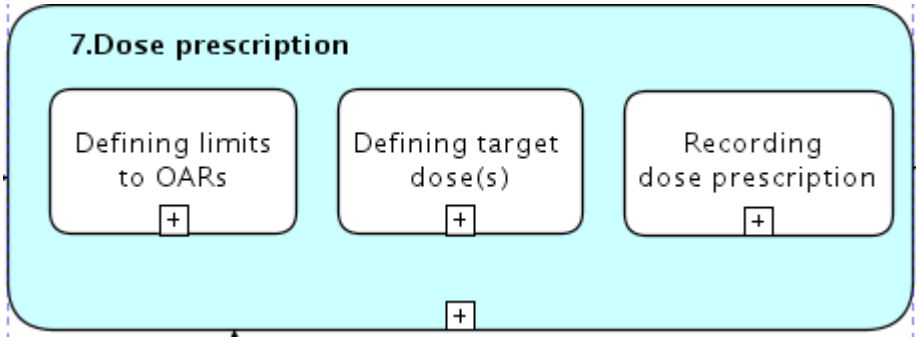

Figure 10. Main tasks in dose prescription process

The limits to organs at risk are based on the medical knowledge and available guidelines.

There is some level of freedom in how to prescribe the target dose for (planning) target volume. Also the dose limits may be different when it comes to clinical trials. Below are some examples how the dose can be prescribed.

- Dose to the isocentre/point;
- Minimum dose to 95% of the target volume;
- Dose to the mean of PTV;
- Minimum dose to the target volume;
- Dose to the 95% of isocentre dose;

Last but not least, the prescribed target doses and limits have to be recorded – either as a print, writing on a special form and/or as a voice recording.

3.8. Dosimetry

The aim of the dosimetry is to create an optimal dose plan that is delivering the prescribed dose to the target volume(s) at the same time respecting the limits defined for organs at risk.

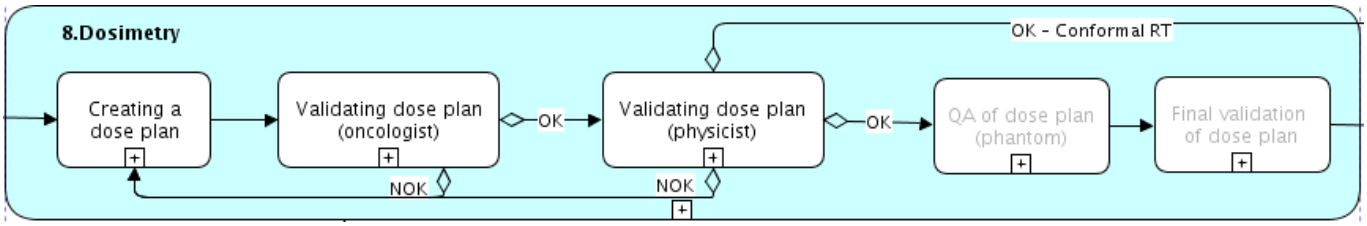

Figure 11. Main tasks in dosimetry process

The main steps in dosimetry are:

- Creating a dose plan
- Validating a dose plan (from oncological point of view)
- Validating dose plan (from physics point of view)
- QA of dose plan (on a phantom)
- Final validation of dose plan

In some countries the validation of the dose plan happens during a meeting (might be also called as multi-disciplinary meeting). Note from a talk with 5th year resident from Germany:

> "The dose plans are first validated by physicist and then at the daily meeting they are discussed."

3.8.1 Creating a dose plan

The aim of this step is to create dose plan. The strategies for dose plan creation are different depending on the treatment type and there are also influences on which treatment machine is used as most of them come with a separate software.

Additional volumes may be created (contoured) to aid the dose plan creation like circle around PTV or OARs.

Direct planning (conformal) is a type of dose planning where the user is adding beams and wedges in the software to shape the dose delivery.

Example times for dose plan creation for 3D conformal RT:

- head, 30-60 min
- lung, 30-60 min
- breast 45-180min

Inverse planning is a type of dose planning where the user decides on the weight (priority) of different regions of interest (tumor(s) or OARs) and the software calculates/optimizes the prescribed dose based on them.

3.8.2 Validating dose plan (oncologist)

The oncologist reviews the dose plan from medical point of view to decide if the dose is covering the target volume and whether the organs at risk are spared as much as possible from excess irradiation. The main tools for this are:

- visual review of the dose distribution compared with the contours delineated
- dose value histogram (DVH)
- isodose contours

In case the dose plan is not created by the (attending) oncologist and he/she is not satisfied with the dose plan created, suggestions are made for dose plan changes. It can lead into negotiation between what can be done with the dose plan and what the oncologist wishes to achieve.

3.8.3 Validating dose plan (physics)

The aim of this step is to ensure that the dose plan created is feasible from physics point of view. It also might include check for accidental mistakes.

Depending on the institution and country the order of validation by oncologist and by medical physicist can be switched – this also changes the exact tasks within these steps.

3.8.4 QA of dose plan (on a phantom)

The aim of this step is to deliver the dose plan on the actual treatment machine to a phantom.

3.8.5 Final validation of dose plan

The aim of this step is to evaluate the dose that was delivered on the phantom is in correspondence with the dose planned.

3.9. Treatment

The first treatment session of a patient is slightly different than the other daily sessions. There is more attention to different steps as the settings for all the following treatment sessions have to be prepared at that step, therefore, its overall length is slightly longer.

Typically a conventional treatment last for 5-6 weeks with 1.8/2Gy per fraction. During that time there might be bodily changes to the patient (e.g., weight loss) and also there is expectation for the tumor to change (e.g., shrinking).

Some patients will have certain pre-requisite before their daily treatment session. For example, for prostate cases the patient should have consistently either a full bladder or an empty bladder (varies between different hospitals) during each treatment session. As such, they might need to drink liquid or empty the bladder before the treatment. During the treatment time there are at least two technicians in the treatment area. One is focusing on tasks on the computers, the other is positioning the patient on the treatment table and doing the communication and monitors the patient during treatment.

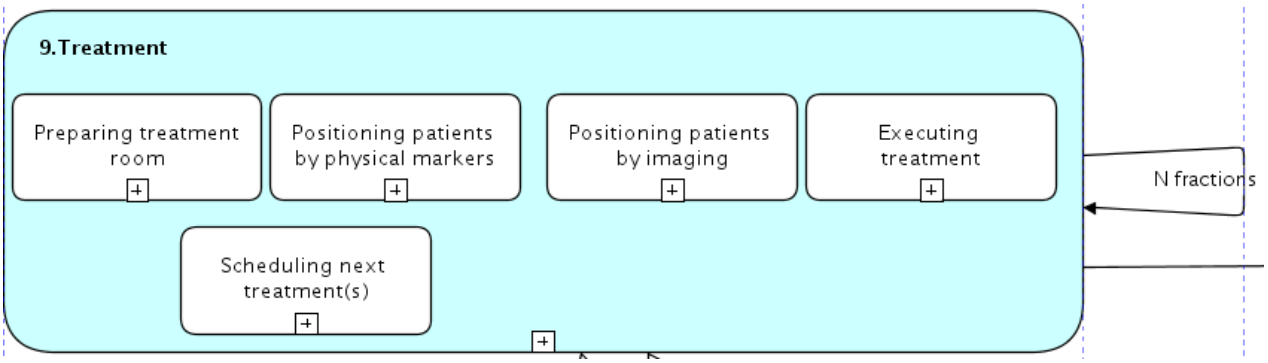

Figure 12. Main steps in treatment

3.9.1 Preparing treatment room

The patient is invited to the changing room while the previous patient is still treated. Patient information retrieval in the software and once the treatment of previous patient is finished the room preparation starts. The treatment room is cleaned from the previous patient and the immobilization items are brought out and prepared. Once the room is prepared the patient is invited into the treatment room.

Treatment accessories, if needed, are attached to the linac (linear accelerator).

3.9.2 Positioning patient by physical markers

Each patient has small markers on body. In the treatment room there are laser beams which are used for the positioning of the patient according to these physical markers.

3.9.3 Positioning patient by imaging

For some type of treatments the patient's position needs to be verified prior to the dose delivery. This is called image-guided radiotherapy (IGRT). All newer linear accelerators have a possibility to acquire electronic portal images. On board imaging can be 2D or 3D. The images can be acquired either as kilovoltage (kV) images or megavoltage (MV) images. In case of 2D images are acquired, they are compared with digital reconstructed radiographs (DRRs) from the planning CT. In case 3D images are acquired (the cone-beam CT), they are compared with the planning CT. The MV images are with the poorest quality, kV images are better but still not as good as DRR.

In addition the image based positioning can happen based on marker match (2D) - for instance the fiducial gold markers which were placed into prostate during planning preparation are used as indicators for evaluating patient's position.

For a simple case the image registration is relatively fast. Sometimes, in case the treatment table cannot be moved automatically, the patient needs to be moved manually and a new portal images have to be acquired. With newer machines manual adjustment is no longer needed, the software automatically detects the shift based on the images, and once it is agreed upon by the technician/radiation oncologist, the shift of the table is done automatically.

3.9.4 Executing treatment

Once the position of the patient has been set and agreed upon the treatment can be delivered. The technician is operating delivery equipment and procedures according to protocol. Some of the tasks the technicians need to do are selecting the right fields, observing the dose delivery indicators and in-vivo dosimetry indicators. For some types of treatment, the patient is re-positioned and/or additional accessories are added to the linac (repeat of steps 9.1/9.2/9.3).

3.9.5 Scheduling next appointments

In parallel to other tasks the next appointments are schedule in the system.

3.10. Validating treatment position images

The patient's position is validated by comparing the planning position and the treatment position. This can be done either directly prior to delivering the treatment or between treatments. In some cases the first validation of the position is done by the technicians, but the oncologist validates between treatments if the positioning is within acceptable shift. The oncologist also often validates the position of other oncologist's patients.

One example scenario of validating treatment position images between treatments is as following:

- Read the patient chart
- Check each taken on-table image against planning CT
- Measure distances on planning CT and positioning image – based on a common point to the edge of the PTV drawn on the image
- How much difference is allowed depends on the margin that is set for the treatment.
- Decision about the treatment images and whether the position is good:
    - If none is good, they will not be verified and suggestion for repositioning is given
    - If one is good, that one will be verified, others will be marked as seen

3.11. Per-treatment follow-up

The radiation oncologist meets with the patient repeatedly (e.g., once a week) to discuss how is the progress of the treatment and to evaluate if there are some side-effects to the treatment.

3.12. Post-treatment follow-up

Once the full treatment has been complete, there will be periodical follow-up meetings to evaluate how was the success of the treatment. Example frequencies of first follow-up meetings:

- Every 2 months for glioblastoma
- Every 3 months for head and neck

Prior to the the follow-up meeting with a medical doctor, the patient needs to get necessary images acquired (MRI, PET etc.). Based on these images the physician needs to evaluate the new images against the past images in order to decide the response to the treatment. The patient's disease can be qualified as: Complete Response (to treatment), Partial Response (to treatment), Stable Disease or Progressive Disease according to imaging and clinical criteria. For instance, in the neuro-oncology field, McDonald criteria and RANO (Revised Assessment in Neuro-Oncology) criteria are used for classifying treatment response.

In case there is doubt whether it is a local relapse site, biopsy might be needed and discussion in multi-disciplinary meeting might happen. It can also be further metastasis. Or it could be side-effect from treatment.

During the post-treatment follow-up the most important thing is to compare different images acquired before and after the treatment, as well as the dose plan that was delivered.

Contouring (delineating volumes) as such usually does not happen during follow-up, unless:

- there will be further treatment
- it's a clinical research case or there is a need to measure
- it's hospital/national policy/physician's preference

4. Conclusions

An overview of the current workflow was given, with a special focus on ‘contouring’. These findings have been presented, discussed and validated by the multidisciplinary partners in the SUMMER project. Nevertheless they can be different in other countries or institutions.

The 12 main steps in radiotherapy work are:

1. Diagnosis
2. Multi-disciplinary meeting
3. External radiotherapy patient consultancy
4. Planning preparation
5. Image fusion
6. Contouring
7. Dose prescription
8. Dosimetry
9. Treatment
10. Validating treatment position images
11. Per-treatment follow-up
12. Post-treatment follow-up

Every step has again many sub-steps, for example, contouring consists of delineating the body, the organs at risk, the gross tumor volume, the clinical target volume, the internal target volume, and the planning target volume. In turn each of these steps again consist of many smaller steps.

In order to (re-)design the User Interface used in radiotherapy treatment planning, detailed understanding of eye-hand coordination and information processing is needed. This workflow is a first step towards building this understanding.

However, only investigating existing situation might not lead into optimal (and innovative) solutions, as such also new human-computer interaction approaches need to be considered (Ramkumar, Varga, Niessen, & Freundethal, 2013). Furthermore, novel user interface details require user testing. For instance, in a pilot testing it was revealed that understanding anatomy in non-orthogonal planes was cognitively demanding for the users (Ramkumar, Varga, Laprie, Niessen, & Freudenthal, 2013). As a result of analyzing current situation and existing opportunities from different domain and conducting thorough testing of solutions, the SUMMER project aims that (at a certain level) the workflow of radiotherapy will change for the better.

The workflow overview served also as a communication aid for the partners and facilitated discussion about projects focus and task distribution between the members. The expectation is that it will provide a good basis for future design work.

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