ESTRO

The WP5 Collective PTPS specifications

ESTRO

1. Introduction

The intention of this document is to aid and inspire those in the procurement process of a treatment planning system for proton therapy (PTPS). It is basically a compilation of aspects addressed in a number of such procurements performed by European particle therapy sites in the last few years.

It is not intended to replace the list of technical and functional specification that should be an important part of a PTPS procurement process but merely act as a source of inspiration and an aid to minimise the risk of forgetting important aspects.

The compilation contains a number of overlaps and sometimes the (more or less) same functionality is repeated and phrased in different ways. There may also be important points missing and in such a case the authors of this report would be grateful to get this information to be able to incorporate these in future editions of this document.

To make the procurement process as smooth and efficient as possible, it is important to make clear to the tenderer if a certain demand *must* be fulfilled, if it *should* be fulfilled or if it merely is a matter of *describing* whether or not a certain functionality is included or not. In the following that distinction is not made and "should" is used in most cases.

Different rules and legislation may be applicable in different countries regarding the procurement process and in particular if it is a matter of a public procurement, the customer must be aware of all these rules. It is not the intention of this document to handle any of the issues concerning legal aspects of the procurement process.

2. General requirements

General description on the PT site
A relatively detailed description of the PT site should be given quite early on. The description should at least include the following information (to the extent it is known at the time of procuring the TPS):

- Type of proton delivery system, including manufacturer, number of treatment rooms, type of nozzles, including details of e.g. movable Range Shifters, different spot sizes, options of passive scattering etc.
- Description of other software packages that will communicate with the TPS, such as oncology information system
- Expected treatment capacity, including expected number of treatment planners and annual number of proton plans
- Any other information regarding the PT site that may influence the bid from the TPS vendor

Introduction
The Proton Treatment Planning System (PTPS) must be designed in accordance with good principles, and the system should be robust and reliable.
The PTPS should accept domestic characters and support domestic keyboards.
The tender should comprise a complete TPS with all necessary components including, but not limited to, import of images including image fusion of different image modalities, target delineation, field application, optimisation, dose calculation, plan evaluation and export of plan data.
The equipment should be CE Marked and comply with radiation protection, health and safety and other relevant legal requirements.

Remote access
For efficient and flexible deployment and user access the system should be remotely accessible e.g. via Citrix and in situations where needed the applications

Safety/Reliability
The proposed solution must be safe for patients, staff and the general public and shall be highly reliable.
The system should be able to continue production even after failure in server hardware components. The PTPS should be a redundant system with duplicated hardware installed in two separated server rooms. If hardware in one server room is not working because of fatal failure, the duplicated hardware should be

in operation within a pre-defined number of hours (a description on how this is fulfilled should be given).
The applications must be able to run on computers with active antivirus software.

Hardware
The tenderer should include a complete hardware package for the PTPS in the tender. The offer should also include hardware for storage. The computing and storage resources should be sufficient for the expected workload at the proton centre.
Server software and client should be possible to host in a virtual environment (e.g. Citrix or VM-Ware) (describe how this is fulfilled)
The PTPS application should also be able to run on standard hospital PC's, e.g. with Microsoft Windows OS version 7 or higher, if necessary with dedicated graphic card.
The offer should include a total of at least [number] work stations for treatment planning.

Licences
The offer shall include enough licenses for all its components to ensure effective use of the PTPS in the described environment.

Integration
The PTPS must be able to seamlessly integrate with and connect to Oncology Management Systems, as described, which will include Record and Verify capabilities.

Reference installations
A track record of successful previous implementation of proton therapy planning systems of similar specification is desirable.

3. Image handling

General introduction

- The PTPS should as a minimum requirement provide tools for import and segmentation of CT, CBCT, MRI, and PET.
- In addition to this, tools for import and segmentation of 4D CT, DWI MRI, DCE MRI, 4D MRI, and 4D PET should be provided.
- The PTPS should support angulated datasets (oblique, sagittal and coronal orientations) and interpret slice spacing correctly.
- The PTPS should support import of FDG-PET standardized uptake value (SUV) data of the major vendors of PET-CT systems; specify which
- The PTPS manufacturer should guarantee support for novel image datasets (e.g. functional imaging as well as functional maps).
- There should be no intrinsic limit on the number of image sets which can be imported.
- Import for dual-energy CT retrieved elemental composition of patient tissues should be supported
- The TPS should provide tools for DRR generation with flexible and configurable imaging geometries (e.g. to support a gantry-mounted 2 BEV x-ray system)
- The TPS should support the export of DRR and other images in DICOM format to the PACS and OIS systems
- The system should meet DICOM compliance for RT Dose object (import and export)

Visualisation

The PTPS should provide 4D image display, processing and fusion tools
The PTPS should provide 3D surface-rendered visualisation of structures
The PTPS should provide 3D volume-rendered visualisation of an image series

Rigid registration

The PTPS should be able to quickly and efficiently register and merge image data from different imaging modalities.

- The PTPS should provide tools for rigid registration (translations and rotations) of CT images to CT, CBCT, PET and MR images. It should be possible to restrict the registration to a user-defined volume (mask)
-

- The PTPS should supply automated structure/contour-based rigid registration
- The PTPS should supply automated point-based rigid registration based on user-defined fiducial points
- Specify the algorithms for rigid registration (e.g. grayscale, volume based, point based etc.). Describe the possibility to select multiple user defined regions of interest (ROIs) for a registration.
- Describe the tools and features for rigid registration of images. E.g. is the naming of the registration unique and descriptive? Is it possible to select/deselect rotation, roll and pitch separately? Is it possible to perform automatic registration between one image and multiple selected images (e.g. planning CT and daily CBCTs)?
- In the interest of retrospective data handling, as many details as possible should be available from the rigid registration matrix.

Deformable registration

- The PTPS should support multi-modality deformable registration of CT, PET-CT and MR datasets
- The PTPS should support structure/contour-based deformable registration
- The underlying algorithms of the deformable registration should be described. The accuracy of the algorithms should be stated. If possible, provide white papers and peer-reviewed literature.
- The PTPS should provide tools for the qualitative and quantitative evaluation of the outcome of the registration, including intuitive graphical tools.
- The PTPS should supply data available for the user from the registration (e.g. transformation matrix, coordinates for structures, volume changes, Dice coefficient, etc.) and allow for visualization of the deformation vector.
- The user-friendliness of the tools and the speed of the deformable registration will be evaluated

Structure propagation

- The PTPS should allow for "structure-propagation": the registration of a floating dataset will result in the definition of a new deformed dataset; structures (i.e. points and delineations) defined on the original floating dataset will be propagated to the deformed dataset
- In case of multiple online/offline rigid registrations, the user should be able to select the registration which should be used for dose propagation. If available, describe the functionality.

- Describe contour propagation from one image to deformedly registered images (e.g. copy of a structure, deformable propagation). Also describe how the history of the contour is tracked to e.g. show from which image the contour originates. Describe the possibility to automatically propagate contours from one image to multiple registered images.
- The TPS must provide rigid and non-rigid propagation of structures across multiple volumetric data sets

HU-conversion

The PTPS should provide flexible handling of HU-SP calibration curves and should in addition provide HU or stopping power (SP) override capability with user defined values within defined structures and/or regions.
The PTPS should have the ability to assign one or several Hounsfield Unit look-up tables to an imaging device e.g. a HU to proton stopping power conversion.
The PTPS should be able to handle CT scanner specific calibrations and editable translation lookup tables of HU to tissue and algorithm specific interaction quantities.

Dose accumulation

In order to perform dose accumulation, the PTPS should support flexibility in the selection of the rigid registration used for dose propagation.

ESTRO

4. Segmentation tools

General introduction

Advanced treatment planning and image guided adaptive proton therapy demands handling of multi-modality imaging and 4D imaging. The PTPS should make available flexible tools for structure contouring on CT, PET, MRI and CBCT including delineation on one image using information from other images registered to the image.

A high patient throughput requires a high efficiency in the target and normal tissue delineation effectuated by e.g. scripting or atlas based and semi-automatic target or structure segmentation. In order to avoid improper treatment, structures generated e.g. by Boolean functions should preferably be automatically updated if the underlying structure is changed.

Automatic contouring using SUV on PET images should be supplied.

The naming of the registrations should be unique and descriptive as well as automatic registration between one image and a series of images is preferred.

The PTPS should allow for the application of user-defined templates with delineation-related settings (e.g. defined structures, names, colours) to facilitate quick setup of new treatment plans

The contouring tools included in the TPS should ease the "delineation-burden" on physicians and technicians. This is especially important in the context of adaptive radiotherapy: without efficient automatic segmentation tools, repeated CT, MRI and PET-CT imaging will result in a prohibitively high image segmentation workload.

The TPS should therefore provide state-of-the-art automated segmentation tools that allow for accurate and fast delineation of large numbers of images. These tools may include the use of anatomical atlases, biomechanical models or a combination of these techniques.

Manual tools

The PTPS shall offer tools for manual contouring and structure delineation

The manual contouring tools should be able to ease the "delineation-burden" on physicians and technicians, and to facilitate efficient and accurate segmentation of patient anatomy

The 2D contouring should be available in all cardinal image planes (axial, sagittal, coronal). When contouring, switching between image planes should be a seamless transition

The PTPS should offer an undo/redo-functionality when performing manual contouring. There should be an undo buffer where a number of delineation actions that can be stored
The PTPS should provide tools for structure editing, e.g. cut, combine, exclude, avoid functions and morphological operations.
The PTPS should allow 2D contours to be interpolated between contiguous image slices
The PTPS should provide tools for post processing of structures (remove holes, remove small contours, reduce number of points etc.), delineation in all three orthogonal planes, etc.

Automatic tools
The PTPS should offer tools for automatic contouring and semi-automatic contouring and structure delineation.
The PTPS should offer an undo/redo-functionality when performing semi-automated contouring
The PTPS should offer tools for HU/grey scale based contour delineation
The PTPS should allow for automatic generation of auxiliary structures by applying 3D margins to existing structures and support growing and shrinking of structures. It should be possible to define anisotropic margins along the positive and negative directions of the cardinal axes (axial, coronal and sagittal)
The PTPS should allow for automatic generation of auxiliary structures by applying Boolean logic (or equivalent) to existing structures. In particular, it should be possible to add and subtract structures.
The TPS should be able to saves the “rules” by which derivative structures are created (3D margins, Boolean logic) as an attribute of the derivative structure
The TPS should provide tools for the support of automatic generation of ITVs based on 4D data sets (e.g. MIP, average position etc.)
The PTPS should provide beam specific PTVs taking inhomogeneities into account.
If a structure is changed, contours based on this structure, e.g. contours created by Boolean algorithms involving the structure, should be automatically updated
It should be possible to manually ‘guide’ the automatic segmentation process for individual cases
The PTPS should allow for subsequent manual editing of automatically generated auxiliary structures

Scripting

The PTPS should provide possibility of scripting of structure generation, describe the functionality.
The PTPS should provide a well-documented API to allow its structure delineation tools to be triggered by external applications or imported scripts

Atlas
The PTPS should provide automated anatomical atlas- and/or model-based segmentation of MRI images
The TPS should allow users to define anatomical atlases and/or models based on their own patient data
It should be stated how the construction of user-defined atlases and/or models is implemented and the database organized
A description of the underlying algorithms for anatomical atlas- and/or model-based segmentation should be provided.
The speed and accuracy of the algorithms for anatomical atlas- and/or model-based segmentation should be given
It should be possible to manually 'guide' the automatic segmentation process for individual cases; describe how this is implemented
It should be stated which anatomical structures are included in the atlases and/or models provided by the tenderer

PET
The PTPS should supply specific tools for contouring PET images
The PTPS should support auto contouring using e.g. SUV values. A description which SUV values are supported, e.g. SUV max, should be supplied.
The PTPS should offer algorithms for automatic segmentation of FDG-PET datasets based on SUV-values that go beyond simple thresholding, in order to facilitate "dose painting by contours"

5. Planning tools

General requirements
The PTPS must support the treatment delivery of Pencil Beam Scanning (PBS) using the stated Proton Therapy System. Treatment planning using state of the art proton pencil beam scanning techniques should be provided. To ensure high level of patient treatment quality and flexibility, effective tools to perform optimization should be available.
The PTPS should provide tools for beam set-up and field geometries, including 3D rendering and BEV displays.
The PTPS should provide tools for the definition and application of 'planning recipes' (standard planning procedures and field geometries)
Dose calculation of treatment records and/or of incomplete fractions (assess dose in case of treatment abortion)
The PTPS should provide the possibility of plan dose summation.

Optimisation
Optimisation should as a minimum be based on dose based constraints (max/min dose, dose-volume constraints etc.) and should allow for multiple constraints for each target or OAR and constraints placed on more than one target/OAR
Describe the optimization process and features (e.g. direct access to DVH parameters during optimization, visualization of fulfilment of clinical goals, calculation of intermediate dose if necessary, possibility to edit fluence etc.). Also describe criteria apart from dose distribution that can be included in the optimization (e.g. smoothness, speed of treatment delivery etc.).
It should be possible to optimise a new proton dose distribution as an additional dose on top of a primary/former dose distribution. If this is possible, describe the functionality.
Specify the PBS techniques supported, e.g. SFUD, distal edge tracking, MFO etc.
Specify which types of constraints are supported in the optimization mentioned above (e.g. min, max, mean, EUD, min/max to a specified volume, dose fall off, multiple constraints/line dose, etc.).
A large variety and flexibility of optimization methods and spot delivery techniques should be supported.
The optimisation should be capable of taking into account simultaneous integrated boosting specific targets.

It should be possible to base a proton plan optimisation on an already given dose distribution, regardless if it is given with protons or photons.
The PTPS should allow for Multi-criteria optimization

Photons
The PTPS should provide tools for treatment planning using photons including dynamic wedges, IMRT and VMAT and electrons. Import of user specific beam data from the [specified machines] should be supported
The referral of patients will for large part be based on comparative dose planning (photon vs. proton). Photon dose planning must therefore also be supported.

DPBN
Dose painting by numbers (functionality): The PTPS should support dose painting by numbers using functional and molecular imaging to determine a voxel by voxel dose. If so, describe the functionality.

Spot pattern and positions
The PTPS should support minimization of scan path e.g. by spot sorting. If so, describe the functionality.
The PTPS should be able to optimize with non-uniform distribution of spot positions and non-uniform energy increments.
Describe default spot patterns (e.g. hexagonal, square, etc.). Is it possible to have user defined spot positions?
Describe how energy layer spacing is set (e.g. automatic according to an algorithm, can it be customized as a parameter for IMPT etc.).
The PTPS should provide methods to automatically reduce the number of spots during optimization.
The PTPS should provide methods to automatically reduce the number of range layers during optimization

Spot weights
The PTPS should provide an intuitive GUI for displaying and manual editing of spot weights
The PTPS should provide tools to constrain spot weights to zero on a per field basis. For e.g. multi-target treatment plans, it should be possible to assign a field to only contribute to a specific target volume. For critical tissues adjacent to target volume, it should be possible to (partially) block the target beam directions where pencil beam pass through the critical structure.

The TPS should provide tools for the flexible definition of machine specific scanning parameters such as maximum scanning extents.
The TPS should provide tools to support varying scanning source to isocentre distances, including infinite, or very large, distances.
Describe how the PTPS handles spots with low weight e.g. if the MU is lower than the Proton systems' minimum MU. The minimum MU per spot should be included during the optimization process.

Robustness
The PTPS should have built-in functionality to evaluate the robustness of a treatment plan for at least a user-defined setup error and range uncertainty combined.
The PTPS should have robust optimization for IMPT as an integrated feature.
Specify the algorithms used for robust optimization (e.g. minimax, mean, hybrid, user defined)
Specify all the options available for robust optimization (e.g. isocenter shift, density change, a full 4DCT scan, additional CT/CBCT scans, specified positional changes in contours, isocenter position, etc.).
The robust optimization should be possible to apply for the dose to the target, as well as for the dose to organs at risk.
The PTPS should allow evaluation of a treatment plan under relative beam-by-beam isocenter variations.
The PTPS should be flexibility in choosing a set of error scenarios (range and/or setup) both in robustness evaluation and robust optimization
The PTPS should provide tools to summarize and display the results of robustness evaluation and make the evaluation of a (robust) treatment plan easy for the dosimetrist, physicist and physician.

Accessories
The PTPS should be able to handle accessories like range shifters, blocks and ripple filters for different snouts and snout-skin distances. Which materials are supported? Describe the degrees of freedom and limitations, e.g. if accessories are plan specific or may be changed between fields.
Multiple beam tunes (spot sizes): Describe how the PTPS supports planning with multiple beam tunes. Is it possible to have several different beam tunes per plan, per field, per energy layer?

Patching
The PTPS should provide tools for patching of fields to cover extended field sizes. The location of the patch lines should be definable by the user.

The PTPS should provide tools for matching of dose gradients for field junctions. Describe what tools are available for this, both with and without gradient smoothing to improve plan robustness.

6. Evaluation and plan documentation

Evaluate and compare plans

- The PTPS should have informative, efficient, and user friendly tools for evaluating plans, and for comparing plans.
- The PTPS should allow comparison of treatment plans with dose distributions (DICOM RT Dose) originating from third parties (e.g. photon therapy treatment plans)
- The PTPS should support dose calculation based on log files from the beam delivery system. It will serve as the dose status in case of partially delivered beams, and as a method to validate the quality of the beam delivery.
- The PTPS should provide dose volume histograms and dose distribution analysis tools.
- The PTPS should have tools to compare two or more plans.
- The PTPS should have tools for evaluation based on modelling of biological response. Response parameters like normal tissue complication rate, tumour response probability, etc., should be accessible and editable.
- The PTPS may be used to estimate the risk for radiation induced secondary cancer.
- The PTPS should have tools to perform an automatic ranking of two or more plans based on user defined decision protocols.
- The PTPS should have tools to evaluate the LET distribution of a plan, and to compare LET distributions between two or more plans.
- The PTPS should be capable of adding dose distributions of two or more treatment plans and visualizing the results (including DVHs)
- The PTPS should be capable of subtracting the dose distributions of two treatment plans and visualizing the results
- The PTPS should accurately calculate DVHs for in steep dose gradients and/or small structures (e.g. optic nerves, chiasm, pituitary gland) by adapting the sampling frequency (or an equivalent solution)
- The PTPS should allow for generation of Beam's Eye View (BEV) images and visualization of spot weight distribution in BEV of organs at risk and targets
- The PTPS should provide tools for displaying dose profiles and for dose-at-a-point querying.
- The PTPS should provide multi-slice (e.g. trans axial, frontal, sagittal and user defined) display of competing dose distributions using colour wash and/or iso-dose contours

- The PTPS should provide dose difference and 2D/3D gamma analysis for comparing different dose distributions
- The PTPS should be able to calculate differential and cumulative dose-volume and dose-surface histograms for defined structures and for combinations of structures.
- The PTPS should provide a comprehensive (and configurable) display of dose volume statistics for any selected structure or structures
- The PTPS should provide tools for recalculating dose on alternative data sets (e.g. repeat CTs) and for comparing these to the nominal treatment plan for the patient
- The PTPS should have tools for comparing plans from different modalities. These tools should include adding and subtracting plans with different dose weights.

Robustness

- Appropriate tools to address robustness should be available.
- The PTPS should have tools to evaluate the robustness of a proton plan to uncertainties related to SPR calibration, isocenter position, intra fractional motions, and inter fractional organ changes.

Plan Check

- The PTPS should support checks for collisions.
- Tools for patient specific QA should be provided e.g. generation of patient specific QA plans for specific test devices

Documentation

- The PTPS should allow for automated production of plan documentation in Portable Document Format (PDF)
- The PTPS should allow the PDF documentation to be customized by the user.
- The PTPS should support to configure standardized reports, for instance by means of templates or scripting
- Following treatment plan data should be included in the documentation (e.g. beam data, couch position, DVHs, graphical representation of dose distribution in orthogonal planes)
- A summary of plan objectives and DVH indices (following ICRU 83) with indication whether objectives are satisfied ("traffic light" functionality) should be included
-

- PDF-documentation of a comparison between two different treatment scenarios (e.g. to provide documentation of superiority of proton over photon therapy for reimbursement purposes) should be provided
- The PTPS should support the printing of dose distributions in a user configurable format and their export in a common image data format (e.g. TIFF, JPG etc.)
- The PTPS should support the printing of DRRs and their export in a common image data format (e.g. TIFF, JPFG etc.)
- The PTPS should support user-configurable plan reports including prescription information, dose distributions and dose to structure statistics (e.g. min/max, mean, D5, V5 etc.). These should be available as PDF documents (or equivalent) and also in XML format.

Other

- The PTPS should allow the user to quickly copy and modify a proton therapy treatment scenario
- The PTPS should be capable of converting isodose volumes to structures that can be exported as DICOM RT Structure objects

7. Motion management

4D data sets

- The PTPS should provide tools to account for respiratory motion by use of images obtained at multiple points during the respiration cycle, e.g. a 4DCT scan.
- A smooth workflow for planning on 4DCT is preferred, including automation of as many steps in the planning process as possible.
- In order to evaluate the effect of organ motion, the PTPS should provide tools for dose propagation to all phases of e.g. a 4DCT scan.
- Automatic generation of MIP (maximum intensity projection), automatic selection of mid-ventilation phase, and automatic propagation of contours from one phase to all phases should be possible
- The PTPS should support dose calculation at all phases (e.g. by dose/structure propagation. individual weighted summation)
- The PTPS should allow any of the phases of the 4D dataset to be used as the “reference” image set for treatment planning
- The PTPS should be capable of generating MIP and AveIP (average intensity projection) images from 4D CT datasets and allow these to be used as the reference image set for treatment planning
- The PTPS should be capable of automatically propagating structures that are delineated on a single phase to other phases in the 4D dataset, taking into account changes in anatomy
- The PTPS should be capable of automatically generation of an “internal target volume” (ITV) from a structure that is defined on all phases of the 4D dataset. An ITV can be assigned to any phase of the 4D dataset and to the MIP and AveIP
- The PTPS should have built-in functionality for recalculating on all phases of a 4D dataset the dose distribution of a treatment plan that was defined on the reference image set
- The PTPS should be capable of computing a cumulative dose distribution by summing the dose distributions of the individual phases of the 4D dataset (or a subset, thereby simulating a gating-window) by means of deformable registration
- The PTPS should provide cine visualization of the 4D dataset and dose distribution.
- The PTPS should be capable of determining the mid-ventilation phase.
- The PTPS should be capable of generating by means of deformable image registration a “mid-position” scan (3D dataset representing the time-

weighted average of the patient anatomy, as described in Wolthaus et al Med Phys. 2008 Sep; 35(9):3998-4011). The mid-position scan can be used as the reference dataset for treatment planning.

4D robust optimization

- It is preferable if the organ motion can be included in robust optimization.
- Robust 4DCT optimization to minimize the interplay effects should be provided. It should be possible to include only selected 4DCT phases used for gating in the optimization.
- The PTPS support robust optimization that minimize effects of interplay on the dose distribution.

Motion Mitigation

- The PTPS should support motion mitigation features of various delivery systems.
- The PTPS should support as many motion mitigation methods as possible to ensure optimal treatment of the large variety of moving targets. E.g. breath hold gating, respiratory gating, re-scanning, tracking, re-tracking, spot size variations, phase controlled spot delivery, motion-robust scan patterns, and ripple filters.
- To maintain high efficiency, repainting as a parameter for plan optimization is preferred.
- The PTPS must support layer and volume repainting.
- The PTPS should support inclusion of repainting as a parameter for plan optimization (e.g. to optimize delivery time).
- The PTPS should handle rescanning (e.g. isolayer, scaled rescanning, phase controlled, volumetric, combination of the techniques, user defined etc.). Describe the available repainting methods in some detail.
- The PTPS should quantify and report the effects of interplay on the dose distribution

ESTRO

8. Physics

- The beam models should preferably have been experimentally validated, and include special issues like handling of accessories, edge scattering on cut blocks, Bragg peak degradation due to inhomogeneities, non-organic implants, and the use of Dual Energy CT – data for optimized determination of Stopping Power Ratio.
- For evaluation of patient safety the PTPS should be capable of modelling neutron doses.
- Various calculation engines for proton therapy should be available (e.g. pencil beam convolution, Monte Carlo simulation)
- The PTPS calculation engines should handle nonorganic implants like metal, Kevlar, silicone implants etc. If possible - provide documentation for experimental validation.
- Provide documented experimental validation for range shifters, blocks and ripple filters for different snouts, snout-skin distances, materials and geometries.
- The PTPS should handle data from a dual energy CT scanner and convert it into SPR information for the dose calculation algorithms.
- It should be possible for the user alone to generate the beam models for the PTPS with appropriate support provided.
- The PTPS should be able to calculate dose distributions for actively scanned proton beams, passive scattered beams and line scanned beams.
- The PTPS should model the nuclear halo at the level of the individual pencil beams
- For dose calculation using a non-Monte Carlo algorithm, the physical pencil beams should be decomposed into finer mathematical beams (usually referred to as bixels or beamlets) in order to take into account the effects of patient tissue inhomogeneities.
- The PTPS should model the variation of the spot size in air at isocenter as a function of proton energy
- Range shifters of various thicknesses should be modelled
- Apertures for pencil beam scanning should be supported.
- The PTPS should be able to model the variation in pencil beam size as a function of the air gap between range shifter and patient.
- The PTPS should provide scan path optimization (e.g. beam delivery dynamics, robustness, rescanning)
- Specify the different optimization algorithms for IMPT (distal edge tracking, single field uniform dose, etc.)

ESTRO

9. Biology

- The PTPS should have informative, efficient, and user friendly tools for evaluating plans, and for comparing plans, also based on biological response modelling.
- Biological response models should preferably include normal tissue complication rate, tumour control rate, variable proton linear energy transfer distribution (LET) dependent relative biological effectiveness (RBE) and risk for radiation induced secondary cancer risk.
- The PTPS should be capable of calculating the 3D LET
- Evaluation of the LET distribution for the entire plan or beam wise provides information of the biological robustness of treatment plans and ideally the LET distribution will be considered in the optimization of the dose distribution.
- The PTPS should allow optimization of LET distribution.
- The PTPS should be capable of correcting the physical dose distribution for RBE with a uniform scaling factor
- The PTPS should be capable of taking into account the 3D LET-distribution and (optionally) tissue composition in a voxel based RBE-correction
- The PTPS should be able to report radiobiological equivalent dose (EQD) for tumour and healthy tissues, modelling the effects of fractionation and variations in overall treatment time according to the standard linear-quadratic model of radiobiology (the parameters can be set by the user)
- The PTPS should able to calculate tumour control probability (TCP) and normal tissue complication probability (NTCP) according to established radiobiological models (the parameters can be set by the user)
- The PTPS should be able to use TCP and NTCP as inverse planning optimization goals
- The PTPS should provide the capability of comparing plans using biological metrics (TCP, NTCP, EUD etc.)
- Additional quantities (besides RBE weighted dose), e.g. LET or LET weighted dose (more physical quantities) should be provided

10. Adaptive Radiotherapy (ART)

Adaptive Radiotherapy (ART) involves adaptation of the treatment plan to anatomical changes during the treatment course. ART is based on images (e.g. CT, CBCT, MRI, PET) acquired during the treatment course, and the PTPS should support the use of the additional information in these images for smooth plan adaptation.

The core feature to be provided by the PTPS in relation to ART is Deformable Image Registration (DIR). High quality DIR is mandatory. Nevertheless, knowing the uncertainties in DIR it also becomes important to be able to monitor, evaluate and control the DIR used for adaptation. This can be done if the PTPS provides tools for visualization, evaluation and user interaction of and with the registration. This should include:

- Deformable image registration (DIR): The PTPS should provide tools to perform DIR between two CT images and between CBCT and CT images.
- Contour propagation: The PTPS should provide tools to propagate contours between deformedly registered images.

Further, the vendor should specify the deformable image registration algorithms available. It should also describe if the algorithms are based on grayscale, anatomical structures, preservation of mass, etc. Evaluation tools for the DIR (e.g. point evaluation for manually selected points and self-consistency checks by back-and-forth mapping or circular mapping through e.g. 4DCT phases) and user interaction should be also described

The PTPS should support an efficient, effective and safe workflow including aspects of ART such as treatment evaluation using CBCT, dose recalculation from the same plan on additional CT images deformedly registered to the planning CT, dose mapping, dose accumulation, and treatment re-planning with inclusion of the dose delivered so far.

The PTPS should support plan selection libraries, where daily pre-treatment imaging is used for online selection of the most suitable plan from a plan library.

An efficient and safe implementation of adaptive workflows not only requires specific capabilities of the TPS, but also of the record-and-verify system. The vendor should provide a description of the available interfaces with commercial R&V systems to facilitate adaptive workflows. The vendor should describe what efforts are being made to develop and maintain such interfaces in the future.

11. Automation, workflow and data integrity

The TPS is expected to have the following basic functionalities:

- The possibility to import/export administrative patient information through a well-defined service interface not only internally but also from/to external centres.
- The possibility to duplicate a patient through a copy action
- The possibility to delete a patient
- The possibility to anonymise a patient
- Archiving functions enabling archived treatment plans to be completely reconstructed in the TPS. The archiving should be operable from all clients in the distributed environment.

To ensure efficient, consistent, user independency and safe workflows, the PTPS must maintain data integrity and provide tools for automation.

- Data integrity is important for maintaining both efficiency and patient safety. The vendor should describe the database or databases used in the PTPS to store and organize data. In general terms specify which database stores which data. Giving special attention to safety for the patient and to prevent unintended events, how does the vendor organize data to ensure minimum redundancy, maintaining unique relations between patient ID, images, dose plans, registrations, etc. across databases.
- Automation includes among others the use of templates, automated segmentation, automated dose planning, and scripting.

To this end the following tools are expected:

- Templates: The PTPS should be able to use various predefined templates/protocols to automate the treatment planning process (this could e.g. include, but is not limited to: names and types of structures, fractionation, location of isocenter, field geometry, optimization criteria, plan objectives, etc.)
- Segmentation: The PTPS should provide tools for automation of segmentation based on CT or MRI images, with specification of the models used for automatic segmentation (e.g. atlas based). Describe the workflow and the possibility of user interaction and customization (e.g. addition of patients/structures to the atlas).
- Multi Criteria Optimization functionality
-

- Automatic treatment planning. Is the PTPS able to base a treatment plan on a library of best-case plans from similar cases (by diagnose and/or anatomical site) in order to optimize the planning process and quality?

A particular attention should be made to scripting. The software should feature the possibility to create and execute user-defined scripts allowing for customizable automation of various procedures. A full description of the scripting language should be made available. Scripts delivered by the vendor as part of this tender need to be specified. Macro recording of scripts should be available.
A further interest is the possibility to use the TPS in “batch mode” and/or “service mode”. By this we mean that the TPS can be configured to automatically execute pre-defined scripts when triggered by external events. This could for example be implemented by allowing the TPS to be started from an external program or by running the TPS as a network service. An example use case would be to have the TPS automatically recalculate a treatment plan on a new CT dataset in an adaptive workflow.
Other scripting options are:

- The scripting language is a high-level imperative programming language with support for procedural and object-oriented programming, advanced container data types (e.g. arrays, dictionaries) and automatic memory management
- The scripting language allows script developers to define their own libraries and to use external third party libraries
- The scripting language allows script developers to call external programs (e.g. shell commands)
- The scripting language allows script developers to create GUI-elements to facilitate interaction with the user
- How are scripts and script libraries managed? How is script development and testing separated from clinical use? Is there an authorization scheme in place? Can scripts be managed on a per-user basis?

The vendor should describe which functionality of the TPS is available for automation.

12. Research, education and training

The vendor should support the implementation of the PTPS by making available application training and preferably provide resources for continuous educational training, knowledge exchange, and access to resources at reference centres.
This includes:

- The vendor should make a beam modelling application specialist available at the site to discuss the provisional beam modelling.
- The vendor should make a beam modelling application specialist available at the site to discuss and/or perform the definitive beam modelling, for at least 1 week continuously during commissioning of the first room.
- Application training: The vendor should provide on-site application training of all relevant staff (radiographers, RTTs, physicists, physicians). Application training includes training in tools, procedures and operations required for segmentation, treatment planning, plan evaluation, data transfer, treatment evaluation, and adaptation.
- Technical training: The vendor should provide training of relevant staff (IT-engineers). Training should include system installation, setup, administration, and optimization. Training for third party virtualization software should also be included.
- The vendor should provide PTPS licenses for non-clinical educational use and training
- The vendor in addition to application training should offer continuous educational programs (on-site training, e-learning, webinars, teaching courses, etc.)

A comprehensive scientific and research collaboration for the development of advanced PTPS tools and systems for pencil beam scanned proton therapy should be agreed. The goals set can only be achieved in a strategic alliance with the supplier of the treatment planning system in which the supplier provides significant financial support to the program. This may include:

- To improve and apply multi-criteria intensity modulated proton therapy (IMPT) planning that is robust against patient setup, range errors, and other sources of errors (e.g. breathing);
- To develop and implement image-guided and biology-guided adaptive workflows including online (near real-time) or offline (ready for the next day) adaptation of the treatment plan to anatomical changes (detected by in-room CTs) and/or to biological changes (measured by offline MRI or PETCT);

- To automatically generate IMPT treatment plans of consistent high quality;
- To improve the accuracy of the proton dose calculation by using dual-energy CT scanning;
- To develop methods (prompt-gamma and time-of-flight PET imaging) for in-vivo proton range and verification and integrate those in the adaptive treatment cycle.

The vendor should support future features of other existing system, and the vendor is asked to disclose their strategy and collaboration about the synchronization of development of new features.

13. Service, Support and Documentation

The customer will require a service and maintenance contract as part of the supply. This should cover hardware and software and mandatory updates. A comprehensive support service will be required.

The PTPS manufacturer should provide

- Comprehensive physics manuals including algorithms, references, file formats, file structures and limitations, including detailed descriptions of the dose algorithms used.
- Comprehensive documentation of their deformable image registration capabilities including algorithms, references, file formats, file structures and limitations.
- All installation/setup and documentation manuals should be electronically available, as well as tech tips and other technical documentation.
- Scripting interface for in-house customizations / development of PTPS extensions
- Full Support Contract on two different levels, including all updates, licenses, service visits and support, including remote on-line support.
- Maintenance and service of the servers and clients must be easy and flexible supported by server and client virtualization, fast and secure backup and archive routines.
- Remote support – as a minimum telephone support (English speaking) with appropriate first-hand technical knowledge of the Equipment and systems, should be available within specified time frames

14. Miscellaneous

Speed
The analytical calculation must be fast enough that, together with the optimisation step. SFUD and IMPT plans should be calculated within clinically acceptable time scales, which for a 1 litre volume and 4 fields should not take longer than [number] minutes.

Dose validation
The TPS should have dedicated tools for fast and easy transfer of treatment plans to phantoms or detector systems for treatment plan verification purposes

Configuration
The PTPS must support the administration and versioning of all parameters characterising proton pencil beams
The PTPS must support multiple, energy dependent depth dose curves with non–regular, and user definable, energy/range separations
The PTPS must support energy dependent, initial angular spatial distributions (IASDs) that can represent both focused and divergent pencil beams

Acceptance testing
The entire system should be subject to a set of acceptance tests. These tests, taken together, will verify that the entire completed system meets all specifications.
The vendor should supply a complete list of acceptance testing procedures.
If the acceptance tests proposed by the tenderer do not cover all essential and relevant issues to verify that the delivered system meets the stated specifications, the Customer reserves the right to add relevant test procedures to the final acceptance testing.