TMIAutomation Reference Guide

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Summary

1. Introduction

This document presents the plug-in script for the Eclipse Treatment Planning System to automate Total Marrow (Lymph-node) Irradiation (TMI/TMLI). Because of the limitations in the couch travel range of linacs (130-150 cm), the TMI/TMLI delivery must be split into two plans with opposite orientations: a head-first supine upper-body plan, and a feet-first supine lower extremities plan. As a consequence, a specific field junction is needed to obtain an adequate target coverage in the overlap region of the two plans at the patient's femoral level [1,2].

The script is written in the C# programming language using the Eclipse Scripting Application Programming Interface (ESAPI) and can be executed within the Eclipse External Beam Planning module.

The script has been designed and tested for Eclipse v15, v16, and v18. The code and binaries are publicly available at https://github.com/nlambriICH/TMIAutomation.

The latest release of the script can be downloaded from https://github.com/nlambriICH/TMIAutomation/releases/latest:

- If you have Eclipse v15, download the zip file *ESAPI15_TMIAutomation-vx.x.x.x.zip*
- If you have Eclipse v16, download the zip file ESAPI16_TMIAutomation-vx.x.x.x.zip
- If you have Eclipse v18, download the zip file ESAPI18_TMIAutomation-vx.x.x.x.zip

The script binaries and configuration files are located in the *Release-15.6, Release-16.1*, or *Release-18.0* directory contained in the zip file according to which version you have downloaded.

If you are on a research workstation (TBox), you can immediately run the script - *TMIAutomation.esapi.dll* - by setting the database in research mode from the RT Administration module of Eclipse. Otherwise, the plug-in script *TMIAutomation.esapi.dll* needs to be **approved** in the Eclipse application.

The software is provided "as is", without warranty of any kind. By using this software, you acknowledge and accept that you bear all responsibility for any risks or damages it may cause. Please review the documentation thoroughly and proceed with caution.

2. Script Overview

2.1 Folder structure

Figure 1 shows the folder structure of the script. The script library *TMIAutomation.esapi.dll* is underlined in red. At the top, there are 6 main folders:

1. Configuration: Contains all the configuration files needed to setup and run the script.
2. Dicoms: The Dicoms used by the deep-learning models to generate the upper-body field geometry should be exported in this folder.
3. dist: Contains the local server which runs the deep-learning models.
4. Docs: Folder containing this document.
5. LOG: Folder where the script logs are saved (created when the script runs for the first time).
6. Schedule: Folder where the isocenter shifts for plan scheduling are saved (created when scheduling a plan).

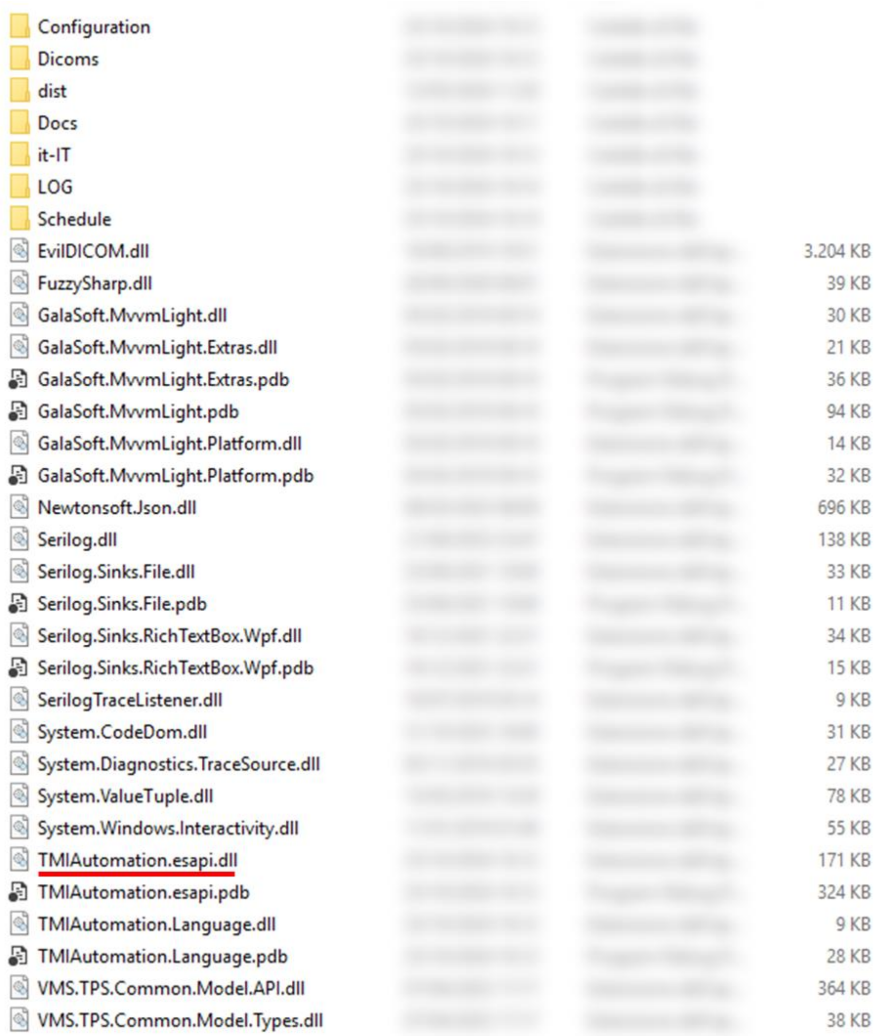

Figure 1: Folder structure of the script (Release-15.6, Release-16.1, or Release-18.0). The file underlined is the dll executable.

2.2 User Interface

Once started, the script presents the user interface shown in Figure 2. The *tab control* is set to *Upper* or *Lower* according to the structure set opened in Eclipse (in context). In both cases, the user can decide which planning step to execute - creation of junction structures, creation of control structures, and plan optimization - by selecting the corresponding *checkboxes* on the interface. If the course selected in Eclipse (in context) contains an upper-body plan and lower-extremities plan with calculated dose, the *Schedule* tab item will be automatically selected when the script starts.

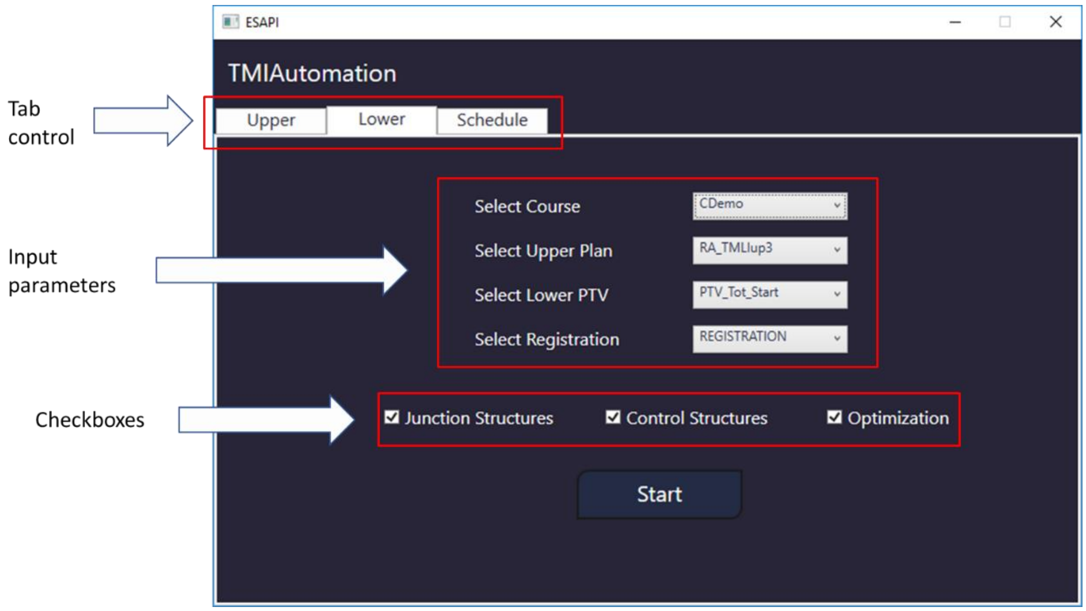

Figure 2: User interface of the plug-in script.

2.3 Upper-body plan

In case Upper is selected from the tab control, the user can create the junction and control structures for the upper-body plan (by selecting the corresponding checkboxes), to obtain a sigmoid dose falloff and avoid potential hotspots at the junction [1,2]. Additionally, the Optimization checkbox will produce the field geometry for plan optimization using a deep-learning model [3].

2.3.1 Requirements

To automatically create the junction and control structures on the upper-body, the script needs:

- An upper-body plan**.**
- A structure set containing the external (BODY) and **upper-body PTV**.

Note: *The junction structures will be created starting from the most caudal slice of the upper-body PTV.*

The user should then select from dropdown menus the following parameters:

- **Course** with the desired upper-body plan.

- **Upper-body plan**.
- **Upper-body PTV**, from which the junction and control structures will be created.

2.3.2 Optimization Structures

Figure 3 shows the main optimization structures generated by the script.

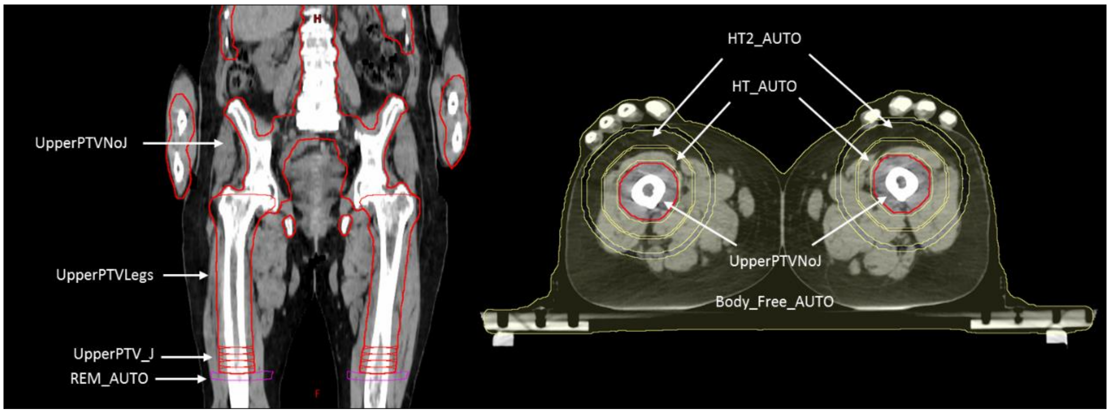

Figure 3: Frontal and transversal views of the main structures generated by the script on the upper-body CT (UpperPTVLegs defines the femoral PTV without the junction structure used for plan scheduling purposes) [1].

Junction Structures

The script executes the following operations when *Junction Structures* is selected on the *checkbox*:

- **Create:** *UpperPTV_J* by considering the volume of the upper-body PTV from the most caudal slice up to a total length of 4 cm in cranial-caudal direction.
- **Split:** UpperPTV_J into four 1 cm thick substructures from bottom to top - *PTV_J25%*, *PTV_J50%*, *PTV_J75%*, *PTV_J100%*.
- **Create**: *UpperPTVNoJ* by subtracting *UpperPTV_J* from the upper-body PTV.
- **Create:** *REM_AUTO* used to reduce the dose near the *PTV_J25%*.

Note: PTV_J25%, PTV_J50%, PTV_J75%, PTV_J100% *are optimized to receive a fraction of the prescribed dose according to their naming convention.*

Control Structures

The script executes the following operations when *Control Structures* is selected on the *checkbox*:

1. **Create**: *HT_AUTO* using the upper-body PTV with an outer margin of 15 mm and inner margin of 3 mm.
2. **Create**: *HT2_AUTO* using the upper-body PTV with an outer margin of 30 mm and inner margin of 17 mm.
3. **Crop**: *HT_AUTO* and *HT2_AUTO* from the external with a 3 mm inner margin.
4. **Create**: *Body_Free_AUTO* from the external using 3 mm inner margin.

5. **Crop**: *Body_Free_AUTO* with the upper-body PTV using a margin of 35 mm.
6. **Remove**: contours whose area on the transversal plane is smaller than 0.5 cm^2 from each control structure.

2.3.3 Plan Optimization

The upper-body plan optimization is executed when *Optimization* is selected on the *checkbox*. Currently, the script supports only the creation of the field geometry [3].

Requirements

The deep-learning models are not shipped with the software due their size. Please contact nicola.lambri@cancercenter.humanitas.it to receive the models and further instructions.

To create the field geometry, the deep-learning model needs the DICOM files of the upper-body CT and structure set. These files should be exported in the directory "Dicoms" where the script executable is located, and inside a directory named by patient Id.

The export can be performed manually or automatically. In the latter case, the Varian Daemon should be configured following the instructions of the Varian API book, Chapter 4 [4]. Afterwards, the specific settings (AETitle, IP, and port) can be changed according to the user specific requirements in the *DCMExport.txt* file inside the Configuration folder.

Field geometry creation

Once started, a window (Figure 4) is shown to the user to confirm or change the selection of OARs (brain, lungs, liver, intestine, bladder) which will be used to create the field geometry. By default, the script pre-selects structure names matching the required structures. The *OARNames.txt* file in the Configuration folder can be modified to add new names and expand the list of potential matching names (because of different naming conventions or language).

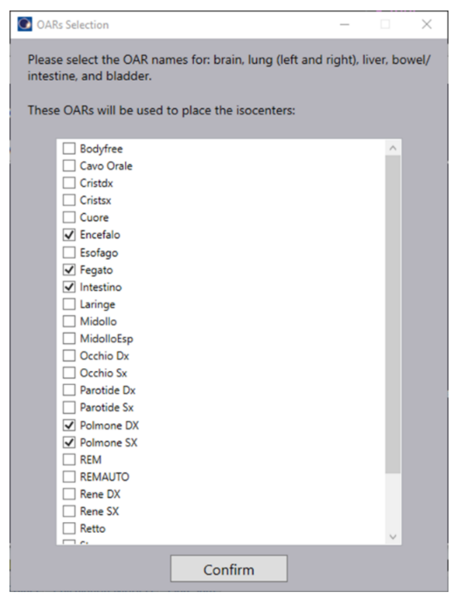

Figure 4: Window shown to the user to confirm or change the selection of OARs used to create the field geometry.

Once the user has selected the correct OARs, the script calls the deep-learning model to generate the field geometry for the upper-body plan. A new upper-body plan named *TMLIupperAuto* (with increasing numbering in case of existing Id) will be created with the generated geometry.

Since version v0.5.1.0, two possible field geometries can be created: one where all fields have the collimator rotated by 90 degrees (Figure 5 [2]) and one where the fields at the pelvic level have collimator rotated by 5/355 degrees, which extends target coverage (Figure 6).

These field geometries are generated by different deep-learning models. By default, the latter geometry is created. The user can select which geometry to create by changing the *coll_pelvis* setting in the config.yml file inside the dist/app folder. When *coll_pelvis: true* (default), the geometry shown in Figure 6 will be created, while *coll_pelvis: false* will produce the geometry reported in Figure 5.

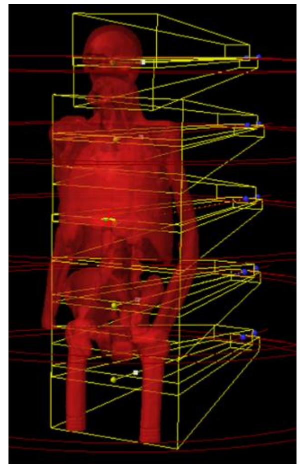

Figure 5: Example of generated field geometry with all collimator angles at 90 degrees.

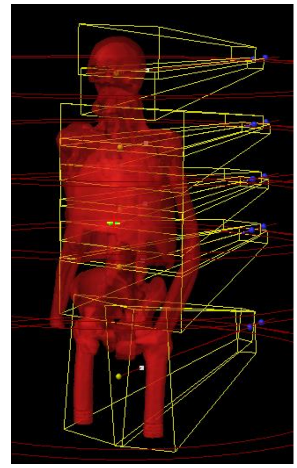

Figure 6: Example of generated field geometry with collimator angle at 5/355 degrees on the pelvis

2.4 Lower-extremities plan

2.4.1 Requirements

To automatically perform the entire planning of the lower-extremities, the script needs:

- An upper-body plan with a **calculated dose.**
- A **registration** of the lower-extremities CT with the upper-body CT.
- A structure set containing the external and **lower-extremities PTV**.

Note: *The lower-extremities PTV can encompass all the bones. The script will remove the volume in excess.*

The user should then select from dropdown menus the following parameters:

- **Course** with the desired upper-body plan.
- **Upper-body plan** with a calculated dose, necessary to create the isodose structures.
- **Lower-extremities PTV**, target from which the junction and control structures will be created.
- **Registration** between upper-body/lower-extremities CTs, to transform the isodose contours between the upper-body CT and lower-extremities CT frame of reference.

2.4.2 Optimization Structures

Figure 7 shows the main optimization structures generated by the script, while Table 1 reports a general description.

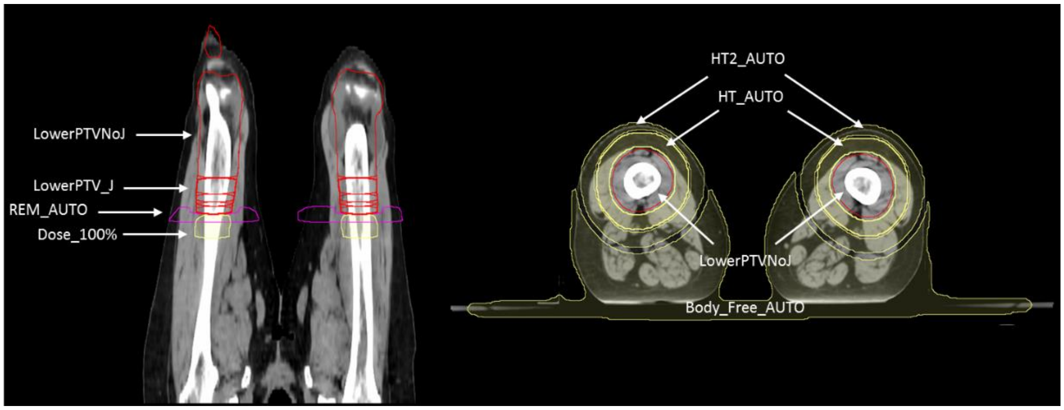

Figure 7: Frontal and transverse views of the main structures generated by the script on the lower-extremities CT [1].

Table 1: Summary of the main structures generated by the script for the lower-extremities plan optimization.

Script phase	Structure	Purpose	Created from
Junction	Dose_100%	Prevent hotspots in the junction region	100% isodose level of the upper-body plan
Junction	LowerPTV_J	Define the lower-extremities junction: it is composed of four substructures (PTV_J25%, PTV_J50%, PTV_J75%, PTV_J100%) each one receiving a fraction of the prescribed dose	Lower-extremities PTV, Isodose levels of the upper-body plan
Junction	LowerPTVNoJ	Target volume used in optimization	LowerPTV_J, Lower-extremities PTV
Junction	REM_AUTO	Reduce the dose near PTV_J25%	PTV_J25%
Control	HT_AUTO HT2_AUTO Body_Free_AUTO	Avoid an excess of dose to the healthy tissues surrounding LowerPTVNoJ	LowerPTVNoJ

Junction Structures

The script executes the following operations when *Junction Structures* is selected on the *checkbox*:

1. **Create**: *Dose_25%*, *Dose_50%*, *Dose_75%*, and *Dose_100%* - i.e., 25%, 50%, 75%, and 100% isodoses using the upper-body plan dose distribution.

2. **Copy**: *Dose_25%*, *Dose_50%*, *Dose_75%*, and *Dose_100%* from the upper-body CT to the lower-extremities CT using the image registration.

3. **Crop**: lower-extremities PTV to the *Dose_100%.*

4. **Create**: *PTV_J25%*, *PTV_J50%*, and *PTV_J75%* where *Dose_75%*, *Dose_50%*, and *Dose_25%* structures intersect the lower-extremities PTV, respectively.

5. **Create**: *PTV_J100%* with thickness of 2 cm above the *PTV_J75%* - toward the feet.

6. **Create**: *LowerPTV_J* as the union of the previous junction substructures (*PTV_Jxx%*).
7. **Create**: *LowerPTVNoJ* by subtracting *LowerPTV_J* from the lower-extremities PTV.
8. **Create**: *REM_AUTO* to reduce the dose near *PTV_J25%.*
9. **Crop**: *Dose_100%* at 3 cm below the junction - toward the head.

Control Structures

The script executes the following operations when *Control Structures* is selected on the *checkbox*:

1. **Create**: *HT_AUTO* using the lower-extremities PTV with an outer margin of 15 mm and inner margin of 3 mm.
2. **Create**: *HT2_AUTO* using the lower-extremities PTV with an outer margin of 30 mm and inner margin of 17 mm.
3. **Crop**: *HT_AUTO* and *HT2_AUTO* from the external with a 3 mm inner margin.
4. **Create**: *Body_Free_AUTO* from the external using 3 mm inner margin.
5. **Crop**: *Body_Free_AUTO* with the lower-extremities PTV using a margin of 35 mm.
6. **Remove**: contours whose area on the transversal plane is smaller than 0.5 cm^2 from each control structure.

2.4.3 Plan Optimization

The lower-extremities plan optimization is executed when *Optimization* is selected on the *checkbox*.

The optimization can be performed with two different approaches based on the Eclipse version:

- Optimization with junction substructures (only Eclipse v15).
- Base-dose planning (all versions).

Note: *Base-dose planning is semi-automatic on Eclipse v15.*

To create a base-dose plan on Eclipse v15, the *BaseDosePlanning* option of the *OptimizationOptions.txt* file should be set to 'Yes'. Otherwise, the script will perform the lower-extremities optimization with junction substructures. We refer to the next sections for the detailed explanation of the two optimization procedures.

Requirements

Depending on which version of the script is used, three **configuration files**, located in the subdirectories of the Configuration folder*,* should be modified before the start of the optimization:

1. *OptimizationOptions.txt*. Contains basic information to configure the optimization process in a tab separated format: *OptimizationAlgorithm*, *DoseAlgorithm*, *MLCID*, *DosePerFraction*, *NumberOfFractions, TreatmentMachine, BaseDosePlanning, AutoPlanLowerExtremities, and LowerExtremitiesCollimator.*

a. *OptimizationAlgorithm* and *DoseAlgorithm* should be set to match the exact names of the corresponding algorithms as they appear in the Eclipse application.

b. *MLCID* should be set to match exactly the *MLCID* of the treatment machine.

c. *DosePerFraction* and *NumberOfFractions* should be set according to the intended prescription.

d. *TreatmentMachine* should correspond to the treatment unit where the plans will be delivered.

e. *BaseDosePlanning* (**only for Eclipse v15** – in other versions, the base-dose plan is always created) should be set to 'Yes' if the user wants to create a base-dose plan.

f. *AutoPlanLowerExtremities* (**only for Eclipse v16 and Eclipse v18**) should be set to 'Yes' if the user wants to perform the full optimization of the lower-extremities.

g. *LowerExtremitiesCollimator* should be set to '90' to create beams with a collimator angle of 90 degrees (Figure 8a) or set to '5355' to create beams with a collimator angle of 5/355 degrees to extend target coverage (Figure 8b).

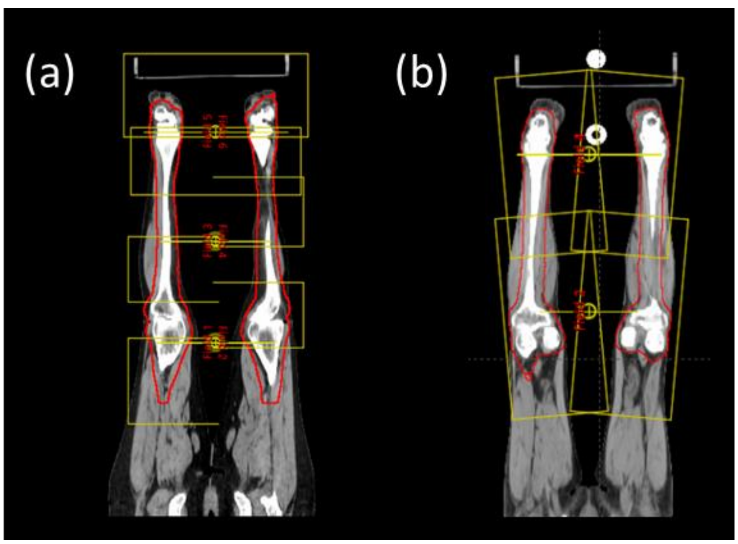

Figure 8: Field geometry generated by the script for the lower-extremities if *LowerExtremitiesCollimator* is set to '90' (a) or '5355' (b).

2. *PointOptimizationObjectives.txt.* Contains the **point dose objectives** for the optimization in a tab separated format: *Structure*, *Limit*, *Volume[%]*, *DoseValue*, *DoseUnit*, *Priority*. Values should be changed according to the optimization needs.

3. *EUDOptimizationObjectives.txt.* Contains the **equivalent uniform dose objectives** for the optimization in a tab separated format: *Structure*, *Limit*, *DoseValue*, *DoseUnit*, *Priority*, *gEUD a*. Values should be changed according to the optimization needs.

Note: *These configuration files are located in the subdirectory TMIAutomation\TMIAutomation\Configuration\ESAPI15,* *TMIAutomation\TMIAutomation\Configuration\ESAPI16, or TMIAutomation\TMIAutomation\Configuration\ESAPI18, according to which version you are using.*

Optimization with Junction Substructures (only Eclipse v15)

The script executes the following operations:

1. **Create:** the plan *TMLIdownAuto* for the lower-extremities.
2. **Place:** two or three isocenters depending on the *LowerExtremitiesCollimator* setting and the PTV cranial-caudal extension.
3. **Optimize:** with intermediate dose calculation, restarting at multi-resolution level 3 (MR3).
4. **Normalize:** the final dose distribution such that 98% of the target volume (*LowerPTVNoJ*) receives 98% of the prescribed dose.
5. **Optimize:** if *LowerPTVNoJ*-Dmean>105%. A new plan - *LowerOptPTV* - is created as a copy of *TMLIdownAuto*. The plan normalization is changed to *LowerPTVNoJ*-Dmean=100% to highlight hot regions in the PTV. The 95% and 105% isodoses are subtracted from *LowerPTVNoJ.* The resulting volumes are used to reduce the hotspots and maintain adequate target coverage.

Note: *When LowerExtremitiesCollimator is set to '90', three isocenters and six full arcs are added with a collimator angle at 90°, ensuring 2-cm overlap between adjacent fields. The isocenters are equally spaced in the cranial-caudal direction and placed at the center of the lower extremities PTV, with the third isocenter on the feet shifted up 3 cm to better cover the feet under the beam of view of the fields (see* Figure 8a*). When LowerExtremitiesCollimator is set to '5355', two isocenters and four full arcs are added with a collimator angle at 5° and 355° for each beam pair (see* Figure 8b*). The isocenters are placed at the center of the lower extremities PTV. If the PTV extension is longer than 65 cm, a third isocenter with a single full arc and a 90° collimator is added to cover the feet.*

Optimization with base-dose planning (all versions)

The base-dose planning approach allows to optimize the lower-extremities without the need of small volume structures (*PTV_Jxx%*). The script executes the following operations:

1. **Copy:** the most caudal isocenter group of the upper-body plan to the lower-extremities using the registration between the CT series
2. **Configure:** the gantry and collimator angle of the fields by taking into account the opposite orientation of the plans.
3. **Create:** the base-dose plan - *LowerBase* - for the lower-extremities.
4. **Calculate:** the dose delivered by the fields using preset MU.
5. **Repeat:** the steps 1-5 of the *Optimization with Junction Substructures* section, using the base-dose plan (*LowerBase*) as reference. However, if the *AutoPlanLowerExtremities* setting is set to 'No', only the steps 1 and 2 are executed. This allows the user to setup the lower-extremities plan and make changes before performing the base-dose plan optimization manually.

6. **Create:** a plan sum - *PSAutoOpt1* - by summing the plan of the upper-body and the most recent one of the lower-extremities.

7. **Optimize:** if *LowerPTV_J*-V98%<98% on the plan sum dose distribution. A new plan - *LowerOptJ* - is created as a copy of the most recent plan of the lower-extremities. The 100% isodose of *PSAutoOpt1* is subtracted from *LowerPTV_J*, and the resulting volume is used to increase the dose coverage.

8. **Normalize:** the final dose distribution such that 98% of the target volume (*LowerPTVNoJ*) receives 98% of the prescribed dose.

9. **Create:** a plan sum - *PSAutoOpt2* - by summing the plan of the upper-body and *LowerOptJ*.

Due to a limitation of ESAPI v15, the steps 5-9 can be executed only on Eclipse v16 and Eclipse v18. With Eclipse v15, the script will create only the base-dose plan *LowerBase* and the *TMLIdownAuto* with the configured field geometry. Then, the user can conduct the base-dose planning optimization manually.

Note: *A new plan* TMLIdownAuto - *and* LowerBase - *is generated each time the script executes one of the previous steps (junction, control, optimization), and a progressive number is appended to the plan name to avoid conflicts.*

2.5 Scheduling

Plan scheduling can be performed by selecting Schedule in the script tab control (Figure 9). To automatically schedule the treatment, the script needs:

- An upper-body plan and a lower-extremities plan with calculated dose**.**
- The **portion of CT images** corresponding to an isocenter group position, with a structure set containing the external (BODY) and upper-body PTV.

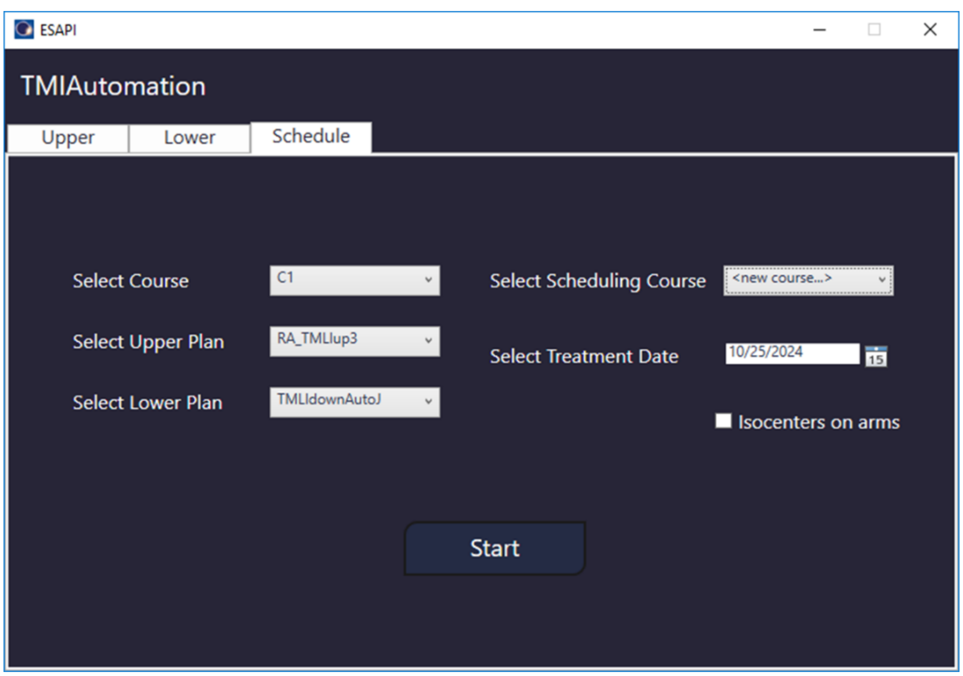

Figure 9: User interface for scheduling.

Then, the user should select from dropdown menus the following parameters:

- **Course** with the desired upper-body plan and lower-extremities plan to be scheduled.
- **Upper-body plan**.
- **Lower-extremities plan**.
- **Scheduling course**: either select “<new course…>” to create a new course with all plans needed for scheduling, or select an existing scheduling course which will be used only to compute isocenter shifts.
- **Treatment date**: select the treatment date (for reporting purposes).

If the field geometry of the upper-body plan has isocenters on the arms, flag the checkbox “Isocenters on arms”. This information is needed to correctly compute the isocenter shifts. Once started, a window (see Figure 10) is shown to the user to confirm or change the selection of the structure sets used for scheduling. By default, the script pre-selects structure sets with “iso” in their name (case insensitive).

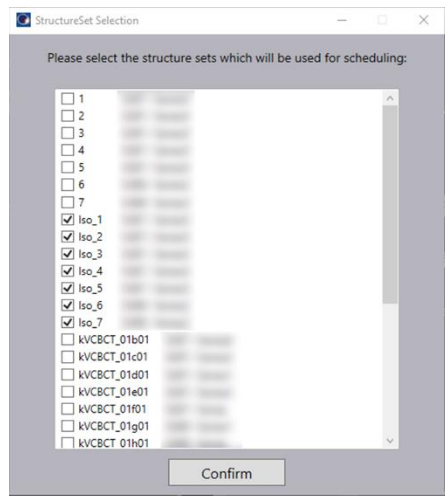

Figure 10: Window shown to the user to confirm or change the selection of structure sets used for plan scheduling.

Then, the script executes the following operations:

1. **Create:** the course where all scheduling plans will be created.
2. **For each structure set:** create the scheduling plan and add the arcs of the corresponding isocenter group.
3. **Add (only for Eclipse v18):** a primary reference point for the currently opened plan and set it as the primary reference point for the created scheduling plan.
4. **Add (only with Eclipse v16 and Eclipse v18):** a CBCT for each isocenter along the body, and a DRR using Bones.dps parameters for the isocenters on the arms.
5. **Calculate:** dose with preset values to obtain the dose distribution for each isocenter group in the structure sets.
6. **Generate:** a text file reporting for each isocenter group the displacements from markers or the adjacent isocenter group (see Figure 11). This file is saved in the Schedule folder where the script executable is located.

Note: *To perform the dose calculations, ensure the OptimizationOptions.txt file contains the correct settings (see 2.4.3 Plan Optimization – Requirements).*

```
Displacements: Isocenters BODY

Most caudal isocenter from markers head: 78 cm
Notes: ...

Isocenter 1: RA_TMLI_ISO1
    With respect to markers head move by:
        2 cm toward left of the patient
        0.1 cm toward back of the patient
        8 cm toward head of the patient

Isocenter 2: RA_TMLI_ISO2
    With respect to isocenter 1 move by:
        20 cm toward feet of the patient

Isocenter 3: RA_TMLI_ISO3
    With respect to isocenter 2 move by:
        22 cm toward feet of the patient

Isocenter 4: RA_TMLI_ISO4
    With respect to isocenter 3 move by:
        23 cm toward feet of the patient

Isocenter 5: RA_TMLI_ISO5
    With respect to isocenter 4 move by:
        21 cm toward feet of the patient


Displacements: Isocenters LEGS

Most caudal isocenter from markers above knees: 41 cm
Notes: ...

Isocenter 6: RA_TMLI_ISO6
    With respect to markers above knees move by:
        1.6 cm toward left of the patient
        3.1 cm toward back of the patient
        10 cm toward feet of the patient

Isocenter 7: RA_TMLI_ISO7
    With respect to isocenter 6 move by:
        4 cm toward front of the patient
        31 cm toward feet of the patient
```

Figure 11: Text file saved in the Schedule folder with calculated isocenter shifts for treatment delivery.

2.6 Log files

During the execution, the script generates log files to trace the operations it performs and report potential errors that might occur. The logs (text files) are located in the *LOG* folder.

3. Release history

- Sep 24, 2025: v0.7.0.0 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.7.0.0
- Apr 21, 2025: v0.6.0.1 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.6.0.1
- Oct 25, 2024: v0.6.0.0 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.6.0.0
- May 13, 2024: v0.5.1.0 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.5.1.0
- Apr 22, 2024: v0.5.0.0 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.5.0.0
- Sep 19, 2023: v0.4.1.2 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.4.1.2
- Jul 10, 2023: v0.4.1.1 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.4.1.1
- Jul 5, 2023: v0.4.1.0 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.4.1.0
- Mar 14, 2023: v0.3.1.2 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.3.1.2
- Dec 22, 2022: v0.3.1.1 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.3.1.1
- Sep 29, 2022: v0.2.2.1 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.2.2.1
- Sep 6, 2022: v0.2 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.2
- Sep 5, 2022: v0.1 https://github.com/nlambriICH/TMIAutomation/releases/tag/v0.1 (pre-release)

4. References

[1] Lambri N, Dei D, Hernandez V, Castiglioni I, Clerici E, Crespi L, et al. Automatic planning of the lower extremities for total marrow irradiation using volumetric modulated arc therapy. Strahlenther Onkol 2022. https://doi.org/10.1007/s00066-022-02014-0.

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