TMIAutomation Reference Guide

Nicola Lambri

Email: nicola.lambri@cancercenter.humanitas.it

ORCID: https://orcid.org/0000-0001-8706-6480

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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.

The script was 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 and v16. 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

The script binaries and configuration files are located in the *Release-15.6* or *Release-16.1* 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 5 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.

Figure 1: Folder structure of the script.

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 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.
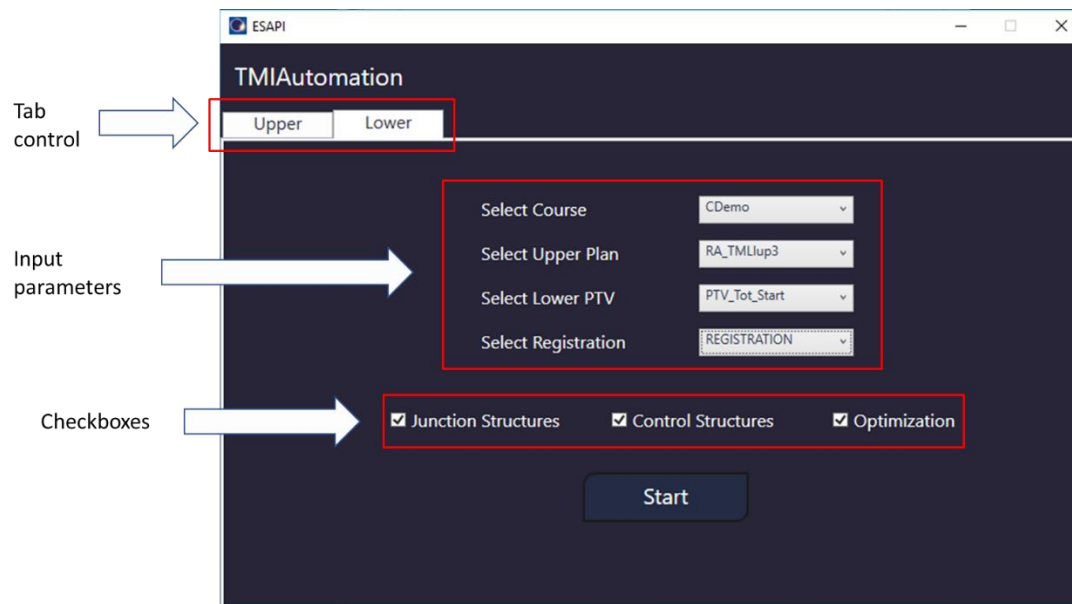

Figure 2: User interface of the plug-in script for the lower-extremities plan optimization.

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]. Additionally, the Optimization checkbox will produce the field geometry for plan optimization using a deep-learning model [2].

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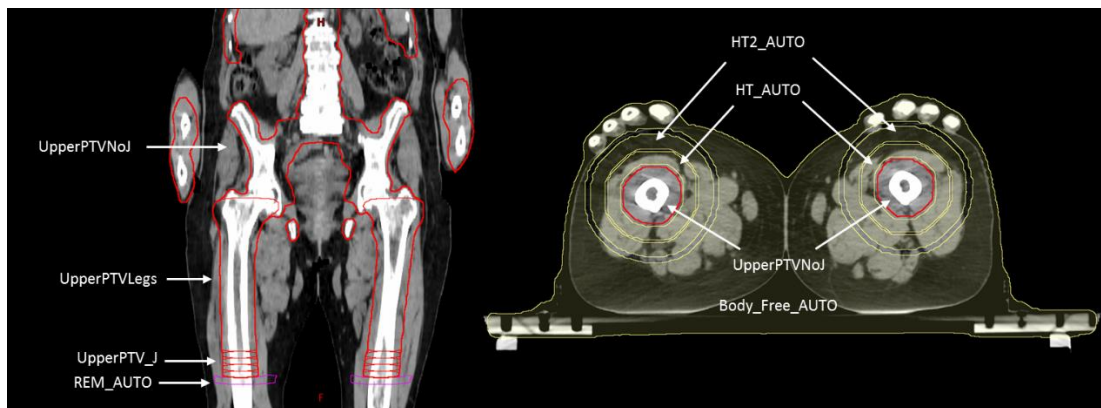
Figure 3: Frontal and transversal views of the main structures generated by the script on the upper-body CT (UpperPTVLegs defines the femoral PTV without the junction structure used for plan scheduling purposes) [1].

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 [2].

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 [3]. 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 (see 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 (approximately) matching those required. 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).

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.

As of version v0.5.1.0, two possible field geometries can be created: one where all fields have the collimator rotated by 90 degrees (see Figure 5 [2]) and one where the fields at the pelvic level have collimator rotated by 5/355 degrees, which extends target coverage (see Figure 6).
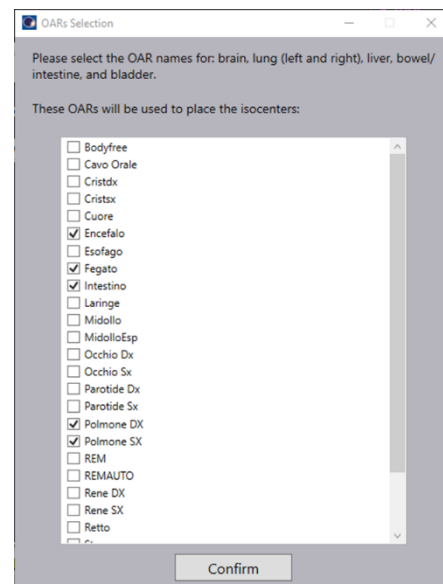
Figure 4: Window shown to the user to confirm or change the selection of OARs used to create the field geometry.

Figure 5: Example of generated field geometry with all collimator angles at 90 degrees.
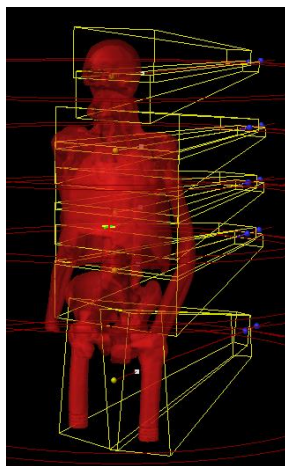
Figure 6: Example of generated field geometry with collimator angle at 5/355 degrees on the pelvis

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. With *coll_pelvis: true* (the default) the geometry shown in Figure 6 will be created, while *coll_pelvis: false* will produce the geometry reported in Figure 5.

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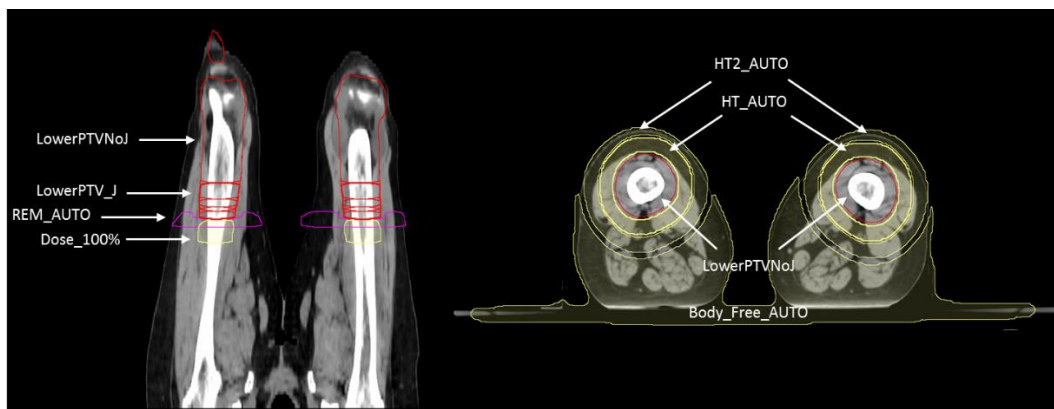
Figure 7: Frontal and transverse views of the main structures generated by the script on the lower-extremities CT [1].

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

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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*:

7. **Create**: *HT_AUTO* using the lower-extremities PTV with an outer margin of 15 mm and inner margin of 3 mm.

8. **Create**: *HT2_AUTO* using the lower-extremities PTV with an outer margin of 30 mm and inner margin of 17 mm.

9. **Crop**: *HT_AUTO* and *HT2_AUTO* from the external with a 3 mm inner margin.

10. **Create**: *Body_Free_AUTO* from the external using 3 mm inner margin.

11. **Crop**: *Body_Free_AUTO* with the lower-extremities PTV using a margin of 35 mm.

12. **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 (Eclipse v15).

- Base-dose planning (Eclipse v15 and v16).

Note: *Base-dose planning is semi-automatic on Eclipse v15 and fully automatic on Eclipse v16.*
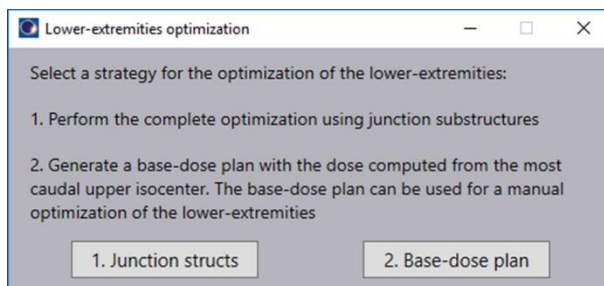
On Eclipse v15, before the start of the optimization process, a window is displayed to the user to choose which optimization approach to follow (see Figure 8). We refer to the next sections for the detailed explanation of the two procedures.

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:

Figure 8: Window shown to the user on Eclipse v15 to choose between: 1. fully automatic optimization (with junction substructures); 2. semi-automatic approach (with base-dose planning).

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

    a. The *OptimizationAlgorithm* and *DoseAlgorithm* names should be changed to match exactly the name of the algorithms as they appear in the Eclipse application.

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

    c. The *DosePerFraction* and *NumberOfFractions* should be set accordingly.

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: *If you are using Eclipse v15 or Eclipse v16, the configuration files to modify are located in the subdirectory TMIAutomation\TMIAutomation\Configuration\ESAPI15 or TMIAutomation\TMIAutomation\Configuration\ESAPI16, respectively.*

Optimization with Junction Substructures (Eclipse v15)

The script executes the following operations:

1. **Create:** the plan *TMLIdownAuto* for the lower-extremities.

2. **Place:** three isocenters and six full arcs with a collimator angle at 90°, ensuring 2-cm overlap between adjacent fields.

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.
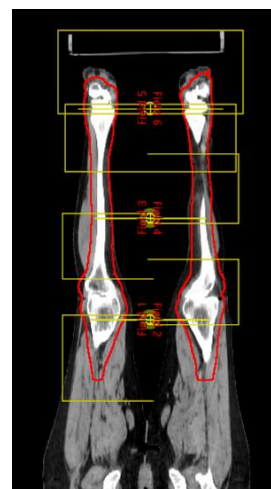
Figure 9: Field geometry generated by the script.

Note: *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 9).*

Optimization with base-dose planning (Eclipse v15 and v16)

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.

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, all the previous steps can be executed only on Eclipse v16. With Eclipse v15, the script will create 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 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
- 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.
[2] Lambri N, Longari G, Loiacono D, Brioso RC, Crespi L, Galdieri C, et al. Deep learning-based optimization of field geometry for total marrow irradiation delivered with volumetric modulated arc therapy. Medical Physics 2024:mp.17089. https://doi.org/10.1002/mp.17089.

[3]   Pyyry J, Keranen W. Varian API Book. 2018.

5. License

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