PHILIPS

Radiation oncology

Treatment planning

# Improving consistency with automated planning algorithms

## Philips Pinnacle Evolution personalized planning

### Introducing the next generation of intelligent automated planning algorithms, featuring advanced tools to deliver a new way of planning

To meet the growing global demand for radiotherapy services and improve the planning process, Philips is investing in new technologies. Philips' latest planning innovation, Pinnacle Evolution, addresses the need to provide therapy plans tailored to the unique clinical/anatomical requirements of each patient – "personalized", high quality IMRT and VMAT plans created consistently and efficiently.

Pinnacle Evolution achieves "Personalized Planning" by combining the latest, Philips-proprietary optimization algorithms[1] with unique personalized goals created by Feasibility technology (Sun Nuclear, Melbourne, FL) and next-generation intelligent, automated planning algorithms (known previously on Pinnacle as "Auto-Planning"). The design goals of the automated planning algorithms and tools are to:

- **Improve** the efficiency of the planning process by removing the repetitive optimization and plan quality tasks found in conventional planning workflows
- **Increase** the consistency of plan quality, regardless of the planner's experience level[2-4] with a robust suite of algorithms
- **Decrease** organ-at-risk (OAR) dose, as much as possible, before target coverage is compromised

# The challenges of conventional planning

In clinical practice, the time to create treatment plans is limited, which makes it challenging to manually develop treatment plans with optimal dose goals for each OAR, while also maintaining both the desired target coverage and the dose to target. Meeting all target constraints and dose goals normally requires multiple iterations. After each of these manual iterations, the planner must manually modify the constraints individually, and manually create many additional structures to minimize inhomogeneous and localized hot or cold spots – created during the optimization process – until a satisfactory dose distribution is achieved. All of these decisions and adjustments for each iteration contribute to inconsistent plan quality and decreased throughput.

However, the consistency of plan quality depends most on the planner's general skills with the treatment planning system.[2] Automated planning provides a way to disseminate, in the form of intelligent algorithms, the best practices of the most skilled planners to all users of the system, thus improving the consistency of plan quality.

## **Automated planning algorithms** do the work of conventional planning

- **Reduce** the need to manually and iteratively create residual dosimetric dose control structures, such as rings, overlaps, hot/cold spots, and maintains user developed planning scripts
- **Balance** the plan quality through multiple iterations of optimization
- **Drive down** OAR sparing beyond initial goals while minimizing impact on target coverage goals

### Simplified consistency with automated planning

There are two common approaches to automating the planning and optimization workflow available: Knowledge Based and multi-criterial optimization (MCO).

Knowledge Based planning is an approach in which a "knowledge base", or library, of high-quality plans are identified and used to estimate how close a new patient is to the dose volume histogram (DVH) of the best plans that had been historically achieved. From those historical best plans, an estimate of that new patient's OAR objectives is made. In addition to requiring substantial upfront work to establish and the ongoing effort to maintain, with knowledge-based planning the user cannot easily incorporate protocol changes, changes to planning techniques, OAR sparing goals and contouring style, without having to manually generate a new library of high-quality plans.[5] Additionally, in cases of complex re-irradiation, knowledge-based planning would be theoretically limited in its application because the unique geometry of each new re-irradiation case is unlikely to have a similar case in the database to which the system can compare.[6]

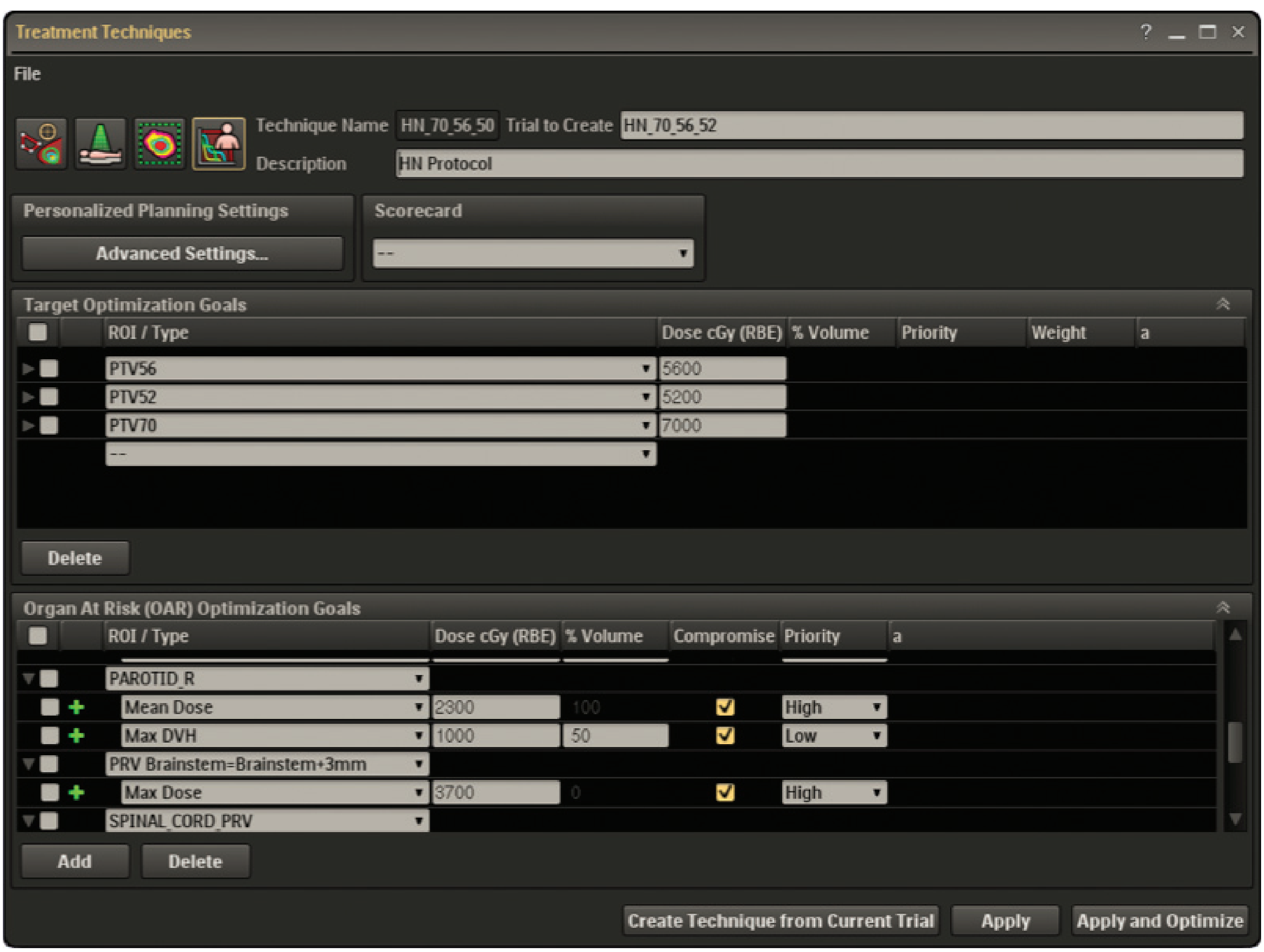
Another approach, multi-criterial optimization (MCO),[7] allows the user to view the effects on plan quality – before optimization – by changing a multitude of different plan objectives simultaneously. This approach has the drawback that it is still a manual process, which can lead to inconsistent results from one plan to the next.[8]

The Automated Planning algorithms in Pinnacle Evolution reduce the manual time spent per treatment plan, since many of the plans may be used clinically without any further optimization.[2-5] Moreover, the automated plans could be used as a high-quality starting point for further optimization of plans to be used in more challenging cases. Pinnacle Evolution's Automate Planning algorithms accomplish this with templates called "Treatment Techniques," and a number of automated optimization tuning methods.

## Treatment Techniques

With Pinnacle Evolution Personalized Planning, the user can define the following automated planning parameters (i.e., clinical goals) in a Treatment Technique:

- Derived ROIs (expanded OAR structures, PTVs, etc.)
- Placement of POIs (points of interest)
- Prescriptions
- Beam geometries, settings and optimization options
- Dose grid settings and isodose line display settings
- Prioritized optimization goals



## Automated optimization tuning methods

In Automated Planning, a "tuning algorithm" attempts to find the most effective balance of OAR sparing and target coverage based on user-defined priorities. First, the algorithm balances OAR and target objectives based on initial user settings and computes an intelligent set of initial OAR weights. Then the algorithm matches the user-desired target coverage and attempts to achieve maximum dose goals that are close but unmet. Other Automated Planning algorithms are designed to:

1. Robustly resolve overlaps of OARs and targets with multiple internal mask representations to avoid creating new derived structures. This avoids the manual process of iteratively creating residual dosimetric dose control structures in Conventional Planning.
2. Improve normal tissue sparing by generating objectives with variable dose levels and weight based on each voxel's distance from the target(s).
3. Intelligently drive OAR sparing as low as can be reasonably achieved, during optimization, beyond what was initially required, while minimizing any compromise on target coverage. Such algorithms for OAR sparing are embedded inside the optimization process, running during fluence mode and segment weight optimization for IMRT and during the refinement stage for VMAT.
4. Consistently remove hot spots from targets during optimization.

## "Optimizing" the optimizer

Automated Planning algorithms more tightly and effectively integrate with the Philips proprietary IMRT and VMAT optimization engine in Pinnacle Evolution. An advantage of this, for example, instead of users having to run the optimizer, stop it, evaluate the results and make modifications, they can now pause optimization to assess the results, change some of the input and resume optimization.

This "Warm start" ability makes the process more efficient, as there is now a single user interface for managing the parameters of the planning process. Simply put, Automated Planning optimizes the function of the optimizer.

## **Next generation** automated planning

### Improved speed & performance

With the introduction of a state-of-the-art, proprietary optimizer in Pinnacle Evolution, (Refer to "Pinnacle Evolution: Improving Performance with Proprietary Optimization" whitepaper for more information) tightly integrating automated planning objectives and tuning algorithms directly into the optimizer offers the opportunity for significantly improved performance.

### More control and versatility

Next generation prescription and dose painting based tools improve control of target conformity, target coverage, dose spillage, normal tissue control and other dosimetric challenges.

### Extended capabilities

More Technique parameters and features have been added, such as isodose lines, dose grid settings, volume-based prescription coverage, normalization and beam parameters.

### Streamlined Workflow

The IMRT planning workflow is improved by integrating IMRT, Automated Planning, plan evaluation, and other information into the main planning user interface. Now, users can simply load their goals from a Technique (or enter them manually) and stay in the same interface. Basic plan evaluation functions can also be accessed from the optimization view such as DVH display controls, score card, view window, etc. All of the overlap and special control structures are no longer necessary or are hidden to avoid clutter in the region of interest and optimization lists.

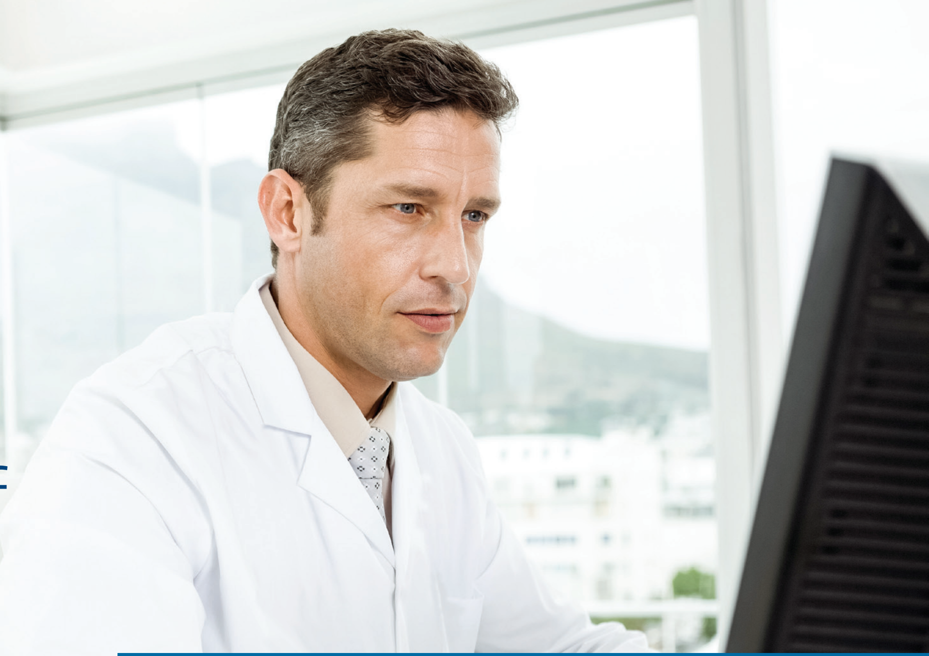
## Conclusion

Pinnacle Evolution delivers next generation automated treatment planning tools and technologies, designed to improve the quality, consistency and efficiency of the therapy planning process. By intelligently automating the conventional planning workflow, and allowing for greater versatility and control, clinicians create plans of consistent quality, from the novice to the expert, from the main campus to satellite locations.

**References**


1. Pinnacle Evolution: Improving Performance with Proprietary Optimization, www.philips.com/pinnacle
2. Nelms, et al. Practical Radiation Oncology v2 n4 p296 2012
3. Hansen et al. Acta Oncologica, 56:11, 1495-1500
4. Krayenbuehl et al. Radiation Oncology (2017) 12:161
5. Hazel, et al. Journal of Applied Clinical Medical Physics, Vol. 17, No. 1, 2016
6. Hansen, et al. Clinical and Translational Radiation Oncology, Volume 1, 2 - 8
7. Seth R. Duffy, Yiran Zheng, Jessica Muenkel, Mary McBride, Rodney Ellis. Refining complex re-irradiation planning through feasibility benchmarking and analysis for informed treatment planning. AAMD 2019 Poster
8. M Monz, K H Kufer, T R Bortfeld and C Thieke Pareto navigation – algorithmic foundation of interactive multi-criteria IMRT Planning. Physics in Medicine & Biology, Volume 53, Number 4.
9. Krayenbuehl, et al, Radiation Oncology 2018


# Pinnacle automated planning clinical proof statements



**Highlights**

- **Physicians prefer Auto-Planning** created plans
- **No compromise in plan quality** with similar target conformity and homogeneity
- **Significant reductions in dose** for many OARs
- **Significant reductions in planning** time enable clinicians to commit more resources to complex cases

## Brain

### Evaluating treatment plan quality and dosimetric differences between Pinnacle Auto-Planning and manual treatment planning in brain cancer patients

Zehren, et al. 2016 AAMD poster submission
http://atlanta2016.medicaldosimetry.org/2016AnnualConference/assets/File/Zehren.pdf

**Conclusions:**

- Treatment planning employing Auto-Planning produces similar, if not better plan quality as compared to previously delivered clinical plans for VMAT.
- The use of Auto-Planning makes the planning process less time consuming and less planner dependent.

### Improved plan quality with automated radiotherapy planning for whole brain with hippocampus sparing: a comparison to the RTOG 0933 trial

Krayenbuehl, et al. Radiation Oncology (2017) 12:161
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5625717/

**Conclusions:**

- Automated treatment planning for HS WBRT was able to fulfil all the recommendations from the RTOG 0933 study
- Achieved significantly-improved dose homogeneity and decreased unnecessary hot spot in the normal brain.
- Achieved standardization of plan quality and minimized the effective time required for plan optimization.
- The effective working time for plan optimization for automated planning of HS WBRT was in the order of five minutes

### Automatic planning on hippocampal avoidance whole-brain radiotherapy

Wang, et al. Med Dosim. 2017 Spring;42(1):63-68
https://www.ncbi.nlm.nih.gov/pubmed/28237294

**Conclusions:**

- Auto-Planning resulted in treatment plans that complied with the dosimetric criteria by RTOG0933.
- 85% of cases were generated by Auto-Planning with a generic Auto-Planning Technique without planners' intervention, whereas the other cases only necessitate slight modification.
- The QA results also revealed that all plans created with Auto-Planning were acceptable for patient care

# Head and neck

## Planning comparison of five automated treatment planning solutions for locally advanced head and neck cancer

Krayenbuehl, et al. Radiation Oncology (2018) 13:170
https://ro-journal.biomedcentral.com/articles/10.1186/s13014-018-1113-z

**Conclusions:**

- The effective working time was kept bellow 20 min for each ATPS except for Raysearch
- Mean effective working time was 5 minutes for Auto-Planning

## Automatic treatment planning improves the clinical quality of head and neck cancer treatment plans

Hansen et al. Clinical and Translational Radiation Oncology 1 (2016) 2–8
https://www.sciencedirect.com/science/article/pii/S2405630816300040

**Conclusions:**

- Pinnacle Auto-Planning achieved superior target homogeneity and target coverage compared with manual planning.
- Organs at risk (OARs) sparing was significantly improved by Auto-Planning for organs.
- Average operator time was halved by Auto-Planning.
- Physicians selected Auto-Planning for clinical treatment in 29/30 patients.

## Automated IMRT planning in Pinnacle: A study in head-and-neck cancer

Kusters JMAM, et al. Strahlenther Onkol. 2017
https://www.ncbi.nlm.nih.gov/pubmed/28770294

**Conclusions:**

- Auto-Planning with IMRT offers similar coverage of the planning target volume as the original manually planned clinical plans (n=20).
- The mean dose of the contralateral parotid gland and contralateral submandibular gland could be reduced by 2.5 Gy and 1.7 Gy on average.
- The number of monitor units was reduced with an average of 143.9 (18%).
- Hands-on planning time was reduced from 1.5-3 h to less than 1 h.

## Evaluation of an automated knowledge-based treatment planning system for head and neck

Krayenbuehl et al. Radiation Oncology (2015) 10:226
https://ro-journal.biomedcentral.com/articles/10.1186/s13014-015-0533-2

**Conclusions:**

- The evaluated Auto-Planning algorithm achieved highly consistent and significantly improved treatment plans
- Potentially clinically relevant OAR sparing by >20 % in 64 % of the cases was observed.
- The effective working time was substantially reduced with Auto-Planning.

## Automatic planning of head and neck treatment plans

Hazell, et al. J Appl Clin Med Phys, 17: 272–282

http://onlinelibrary.wiley.com/doi/10.1120/jacmp.v17i1.5901/full

**Conclusions:**

- Comparison of Auto-Planning and previously delivered clinical plans showed only small dosimetric differences in target coverage,
- Yet, Auto-Planning showed significant reduction in dose to OAR
- The blinded clinical evaluation of the plans showed that, for 94% of the evaluations, Auto-Planning was similar to or better than the clinical plans.

## Automatic treatment planning facilitates fast generation of high-quality treatment plans for esophageal cancer

Hansen et al. Acta Oncol. 2017 Nov; 56(11):1495-1500
https://www.tandfonline.com/doi/full/10.1080/0284186X.2017.1349928

**Conclusions:**

- Pinnacle Auto-Planning was preferred for 31/32 patients in a blinded clinical evaluation.
- Similar target coverage was obtained between Auto-Planning and manual planning methods.
- Median optimization time for Auto-Planning plans was 117 mins

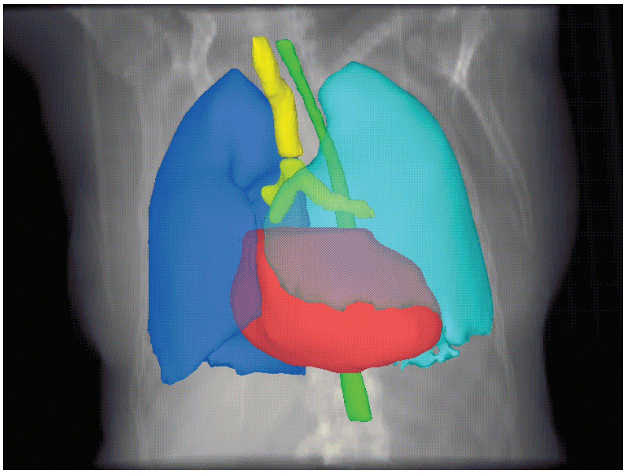
## Initial evaluation of automated treatment planning software

Gintz, et al. J Appl Clin Med Phys 17 (3), 331-346. 2016 May 08
https://www.ncbi.nlm.nih.gov/labs/articles/27167292/

**Conclusions:**

- Auto-Planning excelled at limiting the OAR doses, while still conforming to the relevant RTOG dose homogeneity requirements.
- Auto-Planning appears to be a robust clinical tool

# Thorax and abdomen



## Technical assessment of an automated treatment planning on dose escalation of pancreas stereotactic body radiotherapy

Wang, et al., Technology in Cancer Research & Treatment Volume 18: 1-10
https://journals.sagepub.com/doi/10.1177/1533033819851520

**Conclusions:**

- Auto-Planning consistently and efficiently generate acceptable treatment plans for multitarget pancreas stereotactic body radiotherapy with or without dose escalation
- Acceptable planning target volume coverage for all targets with different prescription levels
- All the plans were generated in a one attempt manner, and very little human intervention is necessary to achieve such plan quality

## Auto- versus human-driven plan in mediastinal Hodgkin lymphoma radiation treatment

Clemente, et al. Radiation Oncology 2018 13:202
https://ro-journal.biomedcentral.com/articles/10.1186/s13014-018-1146-3

**Conclusions:**

- Despite the high interpatient PTV (size and position) variability, it was possible to set a standard AP optimization list with a high level of generalizability for female supradiaphragmatic HL (SHL) treatments.
- Using the implemented list, the AP module was able to limit OAR doses, producing clinically acceptable plans with stable quality without additional user input.
- Overall, the AP engine associated to the arc technique represents the best option for SHL

## Automated Instead of manual treatment planning? A plan comparison based on dose-volume statistics and clinical preference

Vanderstraeten et al. Int J Radiation Oncol Biol Phys, Vol. 102, No. 2, pp. 443e450, 2018
https://linkinghub.elsevier.com/retrieve/pii/S0360301618309155

**Conclusions:**

- Auto-Planning reduced the average optimization time by 77.3%
- Auto-Planning significantly reduced D2% (2% of the volume receives a dose of at least D2%) for the spinal cord, esophagus, heart, aorta, and main stem bronchus ($P < .05$) while preserving target coverage.
- The radiation oncologists found >75% of the APs clinically acceptable without any further fine-tuning.

## A knowledge-based approach to automated planning for hepatocellular carcinoma

Zhang et al. J Appl Clin Med Phys 2018; 19:1: 50–59
https://www.ncbi.nlm.nih.gov/pubmed/29139208

**Conclusions:**

- Statistically significant results showed that automated plans performed better in target conformity index (CI) while mean target dose was 0.5 Gy higher than manual plans.
- Additionally, the doses of normal liver, left kidney, and small bowel were significantly reduced with automated plan. Particularly, mean dose and V15 of normal liver were 1.4 Gy and 40.5 cc lower with automated plans respectively.
- Mean doses of left kidney and small bowel were reduced with automated plans by 1.2 Gy and 2.1 Gy respectively.
- Working time was also significantly reduced with automated planning.

## Auto-planning for VMAT accelerated partial breast irradiation

Marrazzo, et al. Radiotherapy and Oncology 132 (2019) 85–92
https://www.thegreenjournal.com/article/S0167-8140(18)33598-9/fulltext

**Conclusions:**

- PTV coverage and dose homogeneity were improved in AP plans compared to manual.
- A reduction in ipsilateral breast V15 Gy and ipsilateral lung V10 Gy was observed when compared to manual Pinnacle.
- AP for VMAT APBI was proven to be at least equivalent and overall superior to manual planning.

- Planning time was reduced from (54.5 ± 8.0) min for manM planning and (62.8 ± 15.0) min for manP planning to (9.8 ± 1.1) min for AP.

### Comparison of dose metrics between automated and manual radiotherapy planning for advanced stage non-small cell lung cancer with volumetric modulated arc therapy

Creemers, et al. Physics and Imaging in Radiation Oncology, Volume 9, 92 – 96
https://phiro.science/article/S2405-6316(18)30084-8/fulltext

**Conclusions:**

- The treatment plans obtained by automated planning were superior compared to the manually derived plans.
- Significant improvement in Homogeneity Index for the PTV from favoring the automated plans
- Significant reduction of dose delivered to OARs
- Hands-on-time of the manual treatment plans was about two hours, whereas the estimated hands-on-time of the automated treatment plans was only about thirty minutes.

### Evaluation of a commercial automatic treatment planning system for liver stereotactic body radiation therapy treatments

Gallioa, et al. Physica Medica 46 (2018) 153-159
https://www.sciencedirect.com/science/article/abs/pii/S1120179718300188

**Conclusions:**

- Provides top quality plans comparable to those generated manually for liver SBRT treatments.
- Planning times were significantly reduced, thus enabling the planner to use resources for the more complicated treatments.
- The independence of the planner enables to standardize plan quality.
- A specific general technique is adapted to the specific clinical case right before its application to it so to guarantee a personalized treatment care

### Dosimetric benefits of automation in the treatment of lower thoracic esophageal cancer: Is manual planning still an alternative option?

Li et al. Med Dosim. 2017 Winter;42(4):289-29
https://www.ncbi.nlm.nih.gov/pubmed/28754289

**Conclusions:**

- Pinnacle Auto-Planning achieved superior target conformity, homogeneity, and similar target coverage compared with historical manual planning.
- Most of organs at risk (OARs) sparing was significantly improved by Auto-Planning except for the V5 of the lung

### Evaluation of a commercial automatic treatment planning system for liver stereotactic body radiation therapy treatments

Gallio, et al. Physica Medica, Volume 46, February 2018, Pages 153-159
https://www.sciencedirect.com/science/article/pii/S1120179718300188

**Conclusions:**

- Plans created with Pinnacle Auto-Planning were comparable to the manually generated plans.
- Statistically significant differences were observed for spinal cord doses, plan average beam irregularity, number of segments, monitor units and human planning time
- The time saved in planning enables the planner to commit more resources to more complex cases.

### Automated inverse optimization facilitates lower doses to normal tissue in pancreatic stereotactic body radiotherapy

Mihaylov, et al. PLoS ONE 13(1): e0191036
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0191036

The prescription dose to 95% of the planning target volume (PTV) is the same for the treatment and the auto-optimized plans. The average difference for maximum doses to duodenum, bowel, stomach, and spinal cord are -4.6 Gy, -1.8 Gy, -1.6 Gy, and -2.4 Gy respectively. The negative sign indicates lower doses with the auto-optimization. The average differences in the mean doses to liver and kidneys are -0.6 Gy, and -1.1 Gy to -1.5 Gy respectively.

**Conclusions:**

- Automated inverse optimization holds great potential for personalization and tailoring of radiotherapy to particular patient anatomies.
- It can be utilized for normal tissue sparing or for an isotoxic dose escalation.

# Thorax and abdomen (continued)

## Dosimetric comparison between Pinnacle Auto-Planning and manual planning for lung SBRT treatments

Bishop, et al. 2016 AAMD Poster Submission
http://atlanta2016.medicaldosimetry.org/2016AnnualConference/assets/File/Bishop.pdf

**Conclusions:**

- Auto-Planning appears to generate SBRT treatment plans of similar treatment plan quality to manually optimized, clinical plans.
- No statistically significant differences were noted for the dose fall-off parameters.
- Since it provides comparable plans, it can be used as a starting point to standardize plan quality.

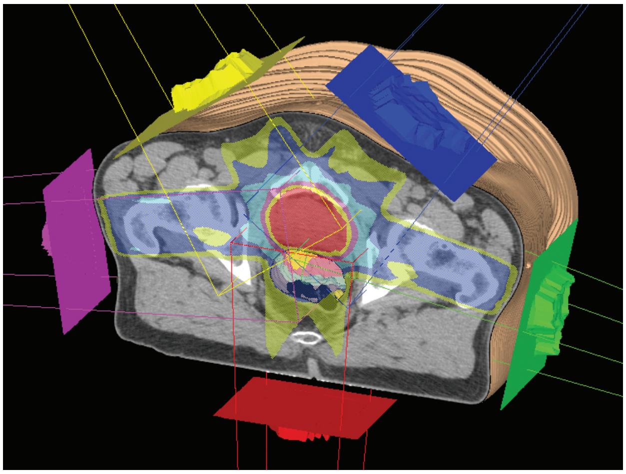
## Improving plan quality and efficiency by automated rectum VMAT treatment planning

Wortel, et al. 2017 ESTRO Poster Submission

**Conclusions:**

- The average Auto-Planning OAR Dmean was 2.5 Gy lower when compared to the manual plans.
- Pinnacle Auto-Planning was unanimously preferred by radiation oncologists and planning dosimetrists.

# Prostate



## Automated VMAT treatment planning for complex cancer cases: A feasibility study

Cilla, et al, World Congress on Medical Physics and Biomedical Engineering 2018. IFMBE Proceedings, vol 68/3
https://link.springer.com/chapter/10.1007%2F978-981-10-9023-3_84

**Conclusions:**

- The Pinnacle Auto-Planning module is capable of efficiently generating highly consistent treatment plans, meeting our institutional clinical constraints.
- AP plans provided significant better conformity and an average decrease in Integral Dose of 6-10%.
- Automated plans also reported a lower variance, thus reducing the inter- and intra-planner variability and achieving higher plan consistency.

## Evaluation of a commercial automatic treatment planning system for prostate cancers

Nawa, et al. Med Dosim. 2017 Autumn;42(3):203-209
https://www.ncbi.nlm.nih.gov/m/pubmed/28549556/

**Conclusions:**

- Planning target volume (PTV) dose and dose to rectum were comparable between Pinnacle Auto-Planning and manual planning.
- Auto-Planning significantly reduced the dose to the bladder and femurs.
- For prostate cancer, the Auto-Planning module provided plans that are better than or comparable with those of manual planning.

## Evaluating treatment plan quality between manual planning and Auto-Planning in patients with prostate and seminal vesicle irradiation

Marston, et al. 2016 AAMD Poster Submission
http://atlanta2016.medicaldosimetry.org/2016AnnualConference/assets/File/Marston.pdf

**Conclusions:**

- All structures except the penile bulb, had a statistically significant reduction in Dmean.
- The bladder and femoral heads showed an improvement in D2cc.
- The rectum, bladder, sigmoid, and small bowel all showed improvement in the V40%.
- Auto-Planning appears to facilitate the treatment optimization process all the while making the overall planning process less laborious and time consuming

## Investigating the dosimetric differences between clinical planning using volumetric modulated arc therapy and Auto-Planning in Patients with cancer of the prostate and pelvic lymph nodes

Lirani,, et al, AAMD 2016 Poster submission
http://atlanta2016.medicaldosimetry.org/2016AnnualConference/assets/File/Aziz.pdf

**Conclusions:**

- Pinnacle Auto-Planning can help the planner meet certain dose constraints that might be more difficult to achieve with regular VMAT plans.
- In examining the OARs, nearly all structures had less overall mean dose.
- Reducing dose to structures is critical when it comes to sparing OAR function and limiting the side effects of radiotherapy on patients.
- Auto-Planning can make treatment planning less laborious and time consuming, while providing comparable or significantly improved outcomes than VMAT plans done manually.

***There's always a way to make life better.***
**www.philips.com/pinnacle-evolution**

Printed in The Netherlands
4522 991 52991 * SEP 2019