Is IMPT still superior to 3D conformal proton therapy (3DCPT) in the presence of setup errors and range uncertainties?

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Sensitivity analysis for two patients

Sites

- Paraspinal case
- Skull-base case

Nominal plans

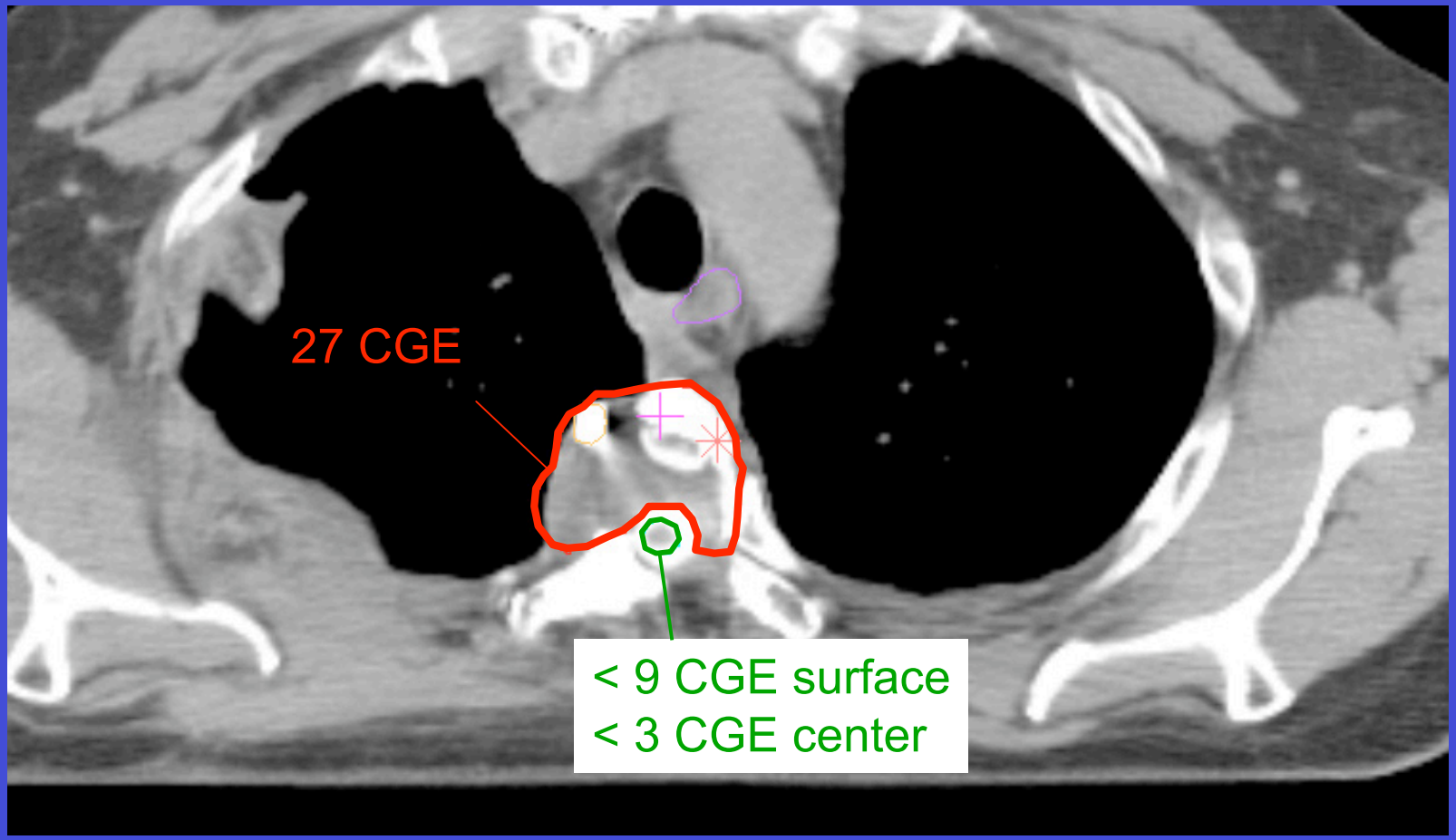
- Clinical plan (3DCPT): XIO, CMS → Set of RC and apertures
- IMPT plan: KonRad Pro → Set of intensity maps

Sensitivity analysis

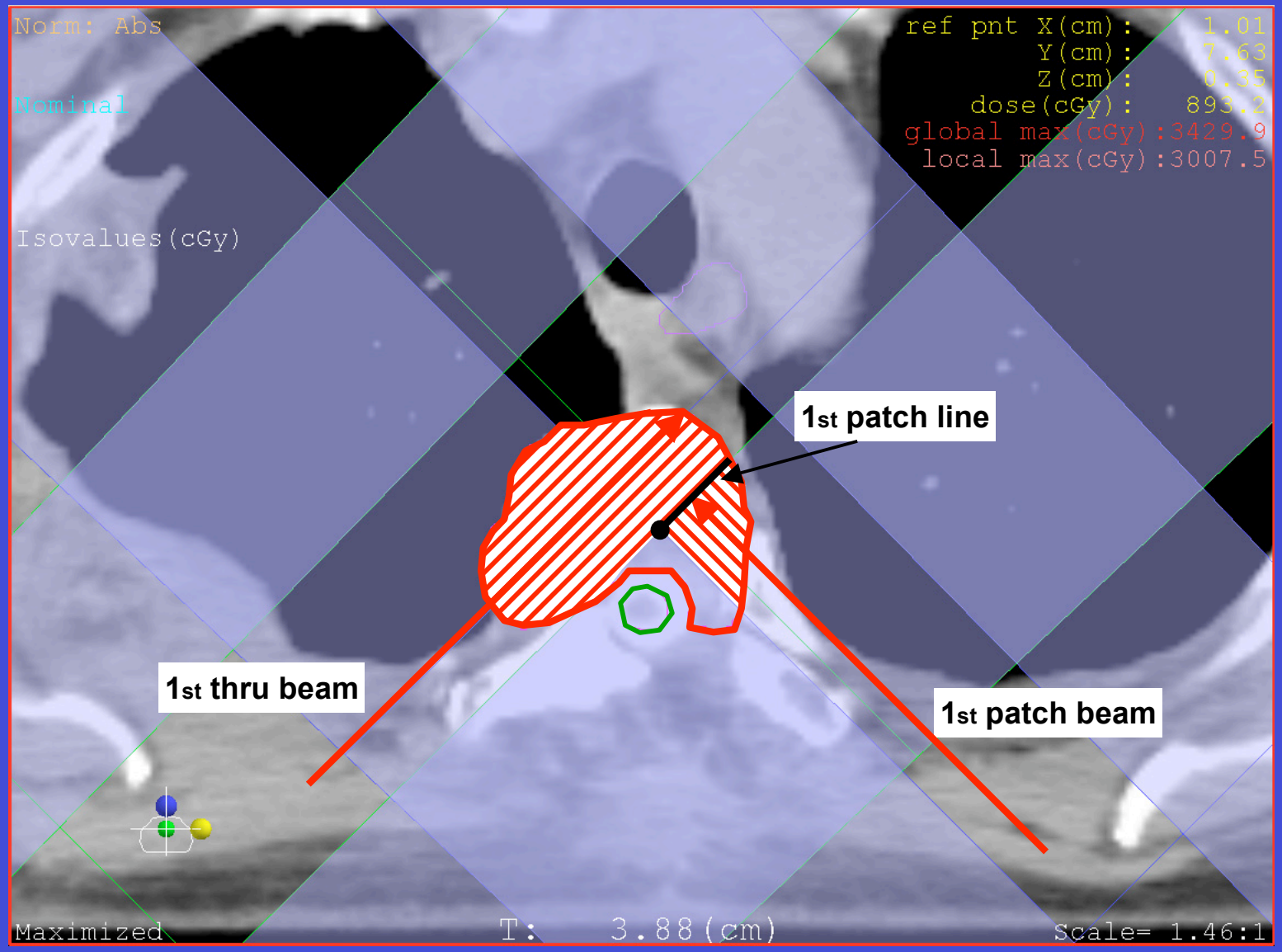
- Setup errors: beam isocenter shifted by ±1 mm in x,y,z
- Range uncertainties: nominal range changed by ±2.5 mm

1st Clinical example: the paraspinal case

- Multiply recurrent G2 chondrosarcoma T4
- 4 fields (Boost: 27 CGE with protons)
- 2 patching combinations (4 fields)



1st Clinical example: the paraspinal case



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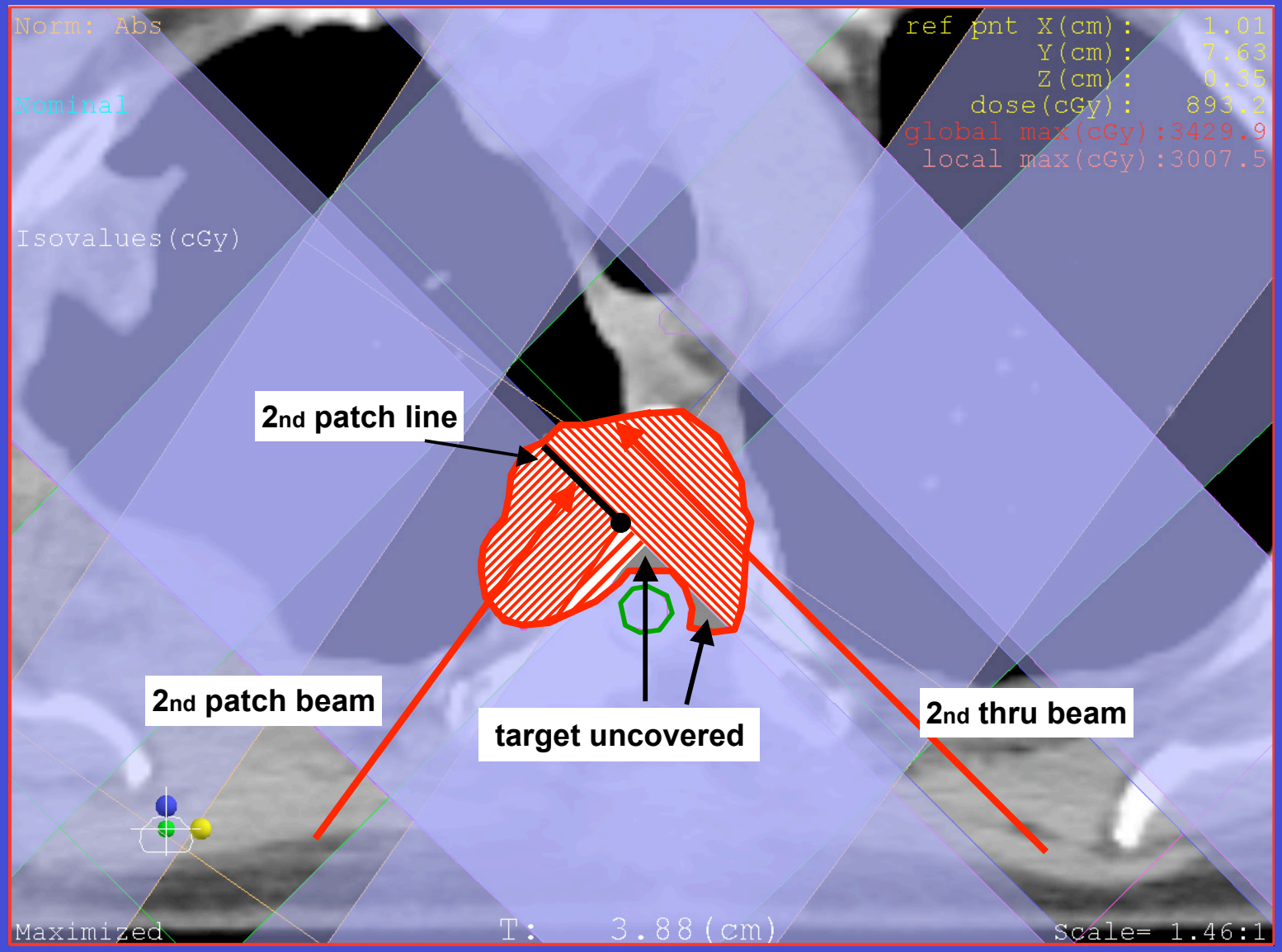

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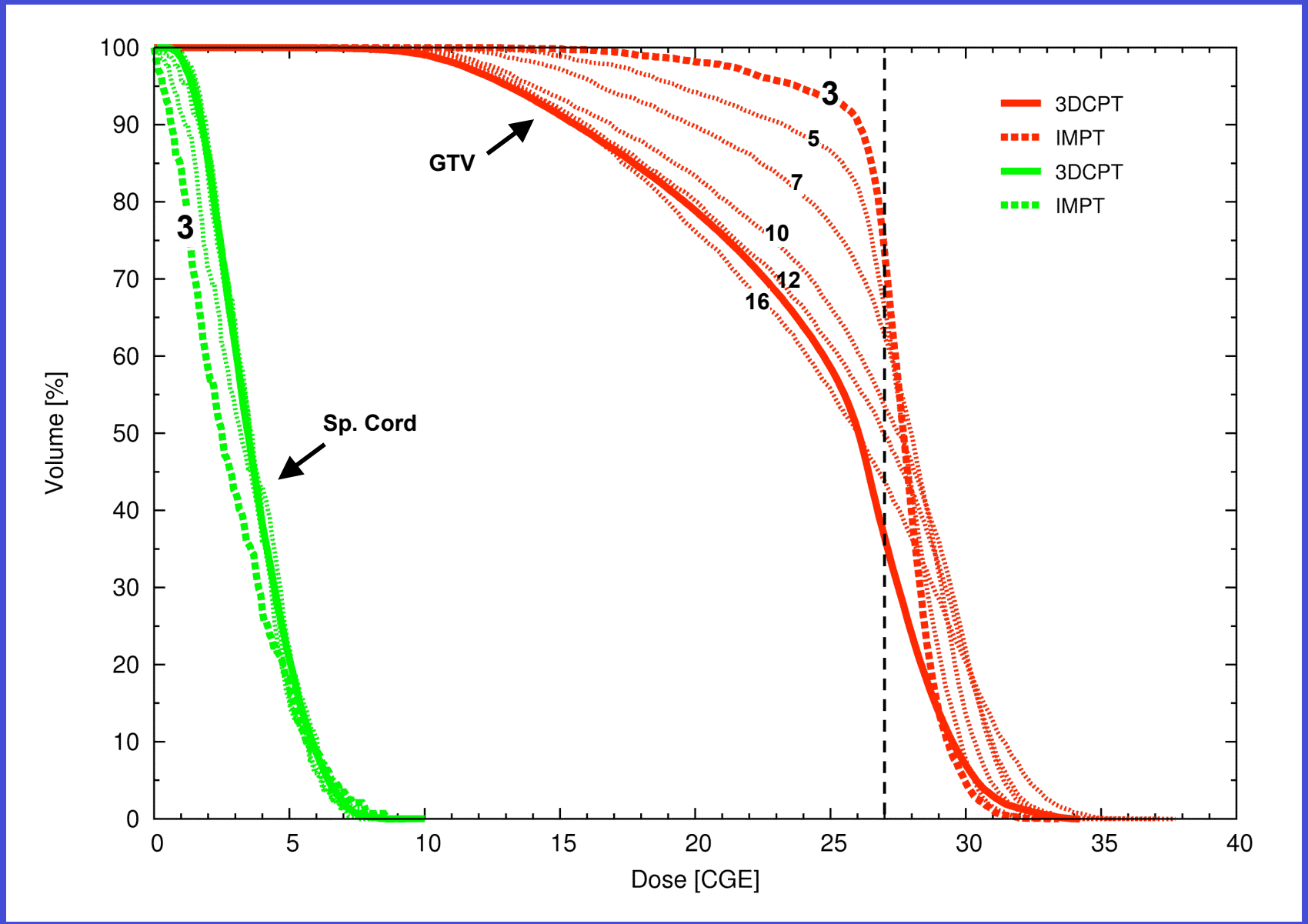
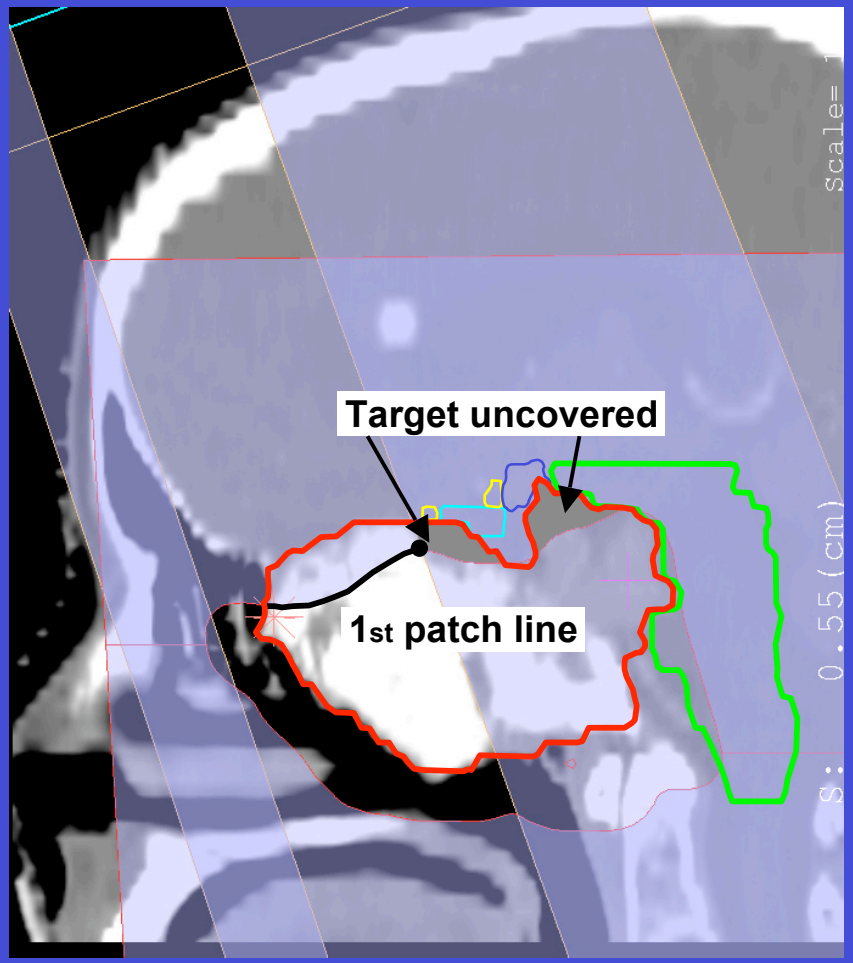
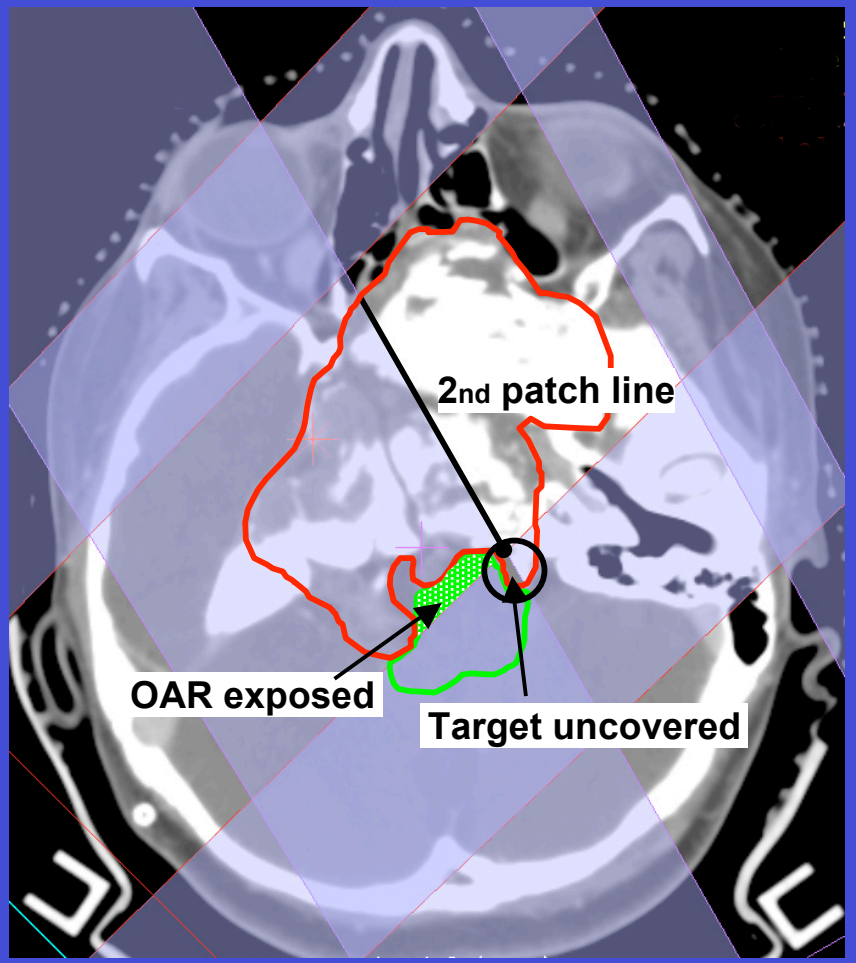


2nd Clinical example: the skull-base case

- Skull-Base Chondrosarcoma
- 9 fields (69 CGE)
- 2 patching combinations (5 fields)

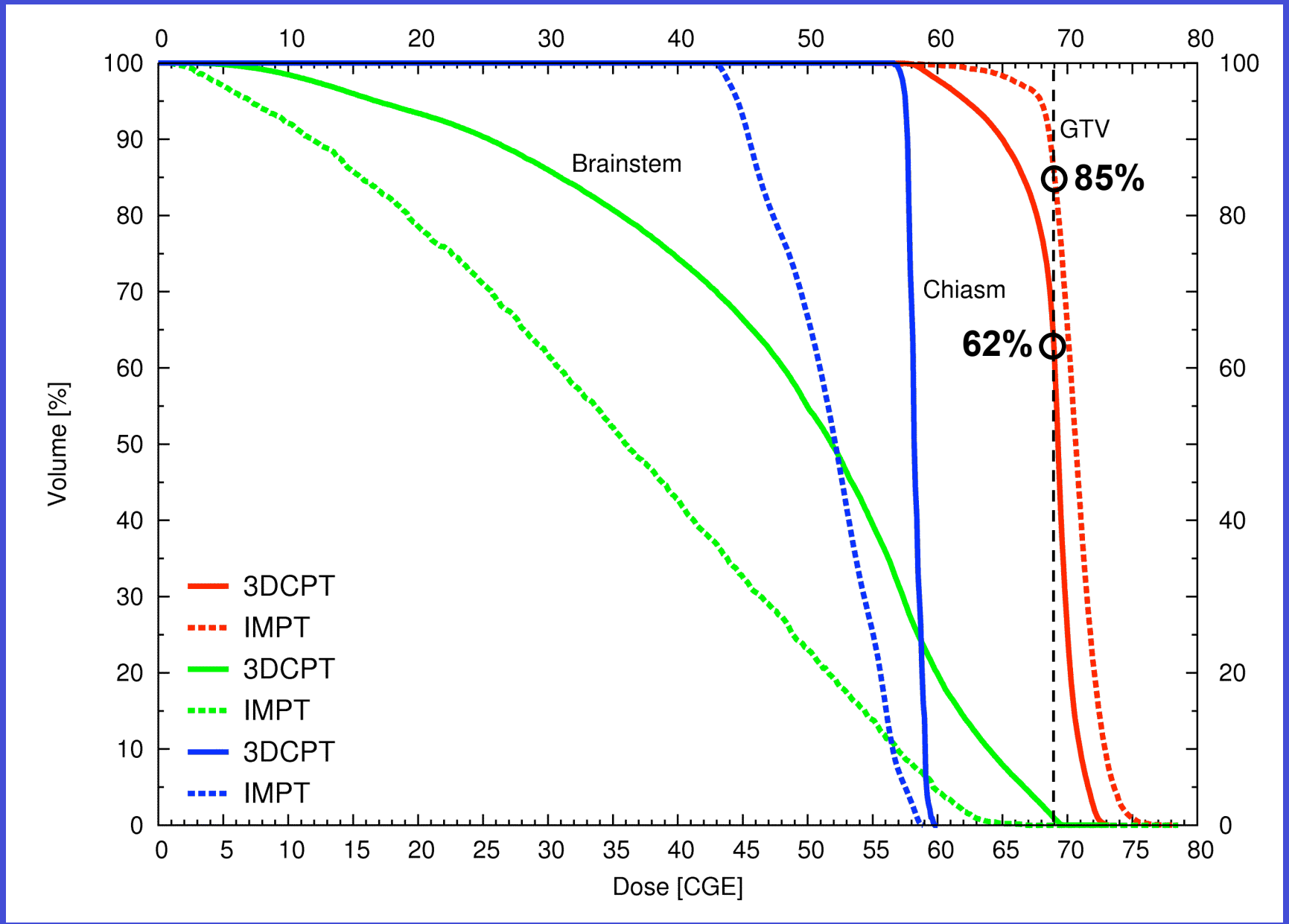


Sagittal view



Transversal view

2nd Clinical example: the skull-base chondrosarcoma case



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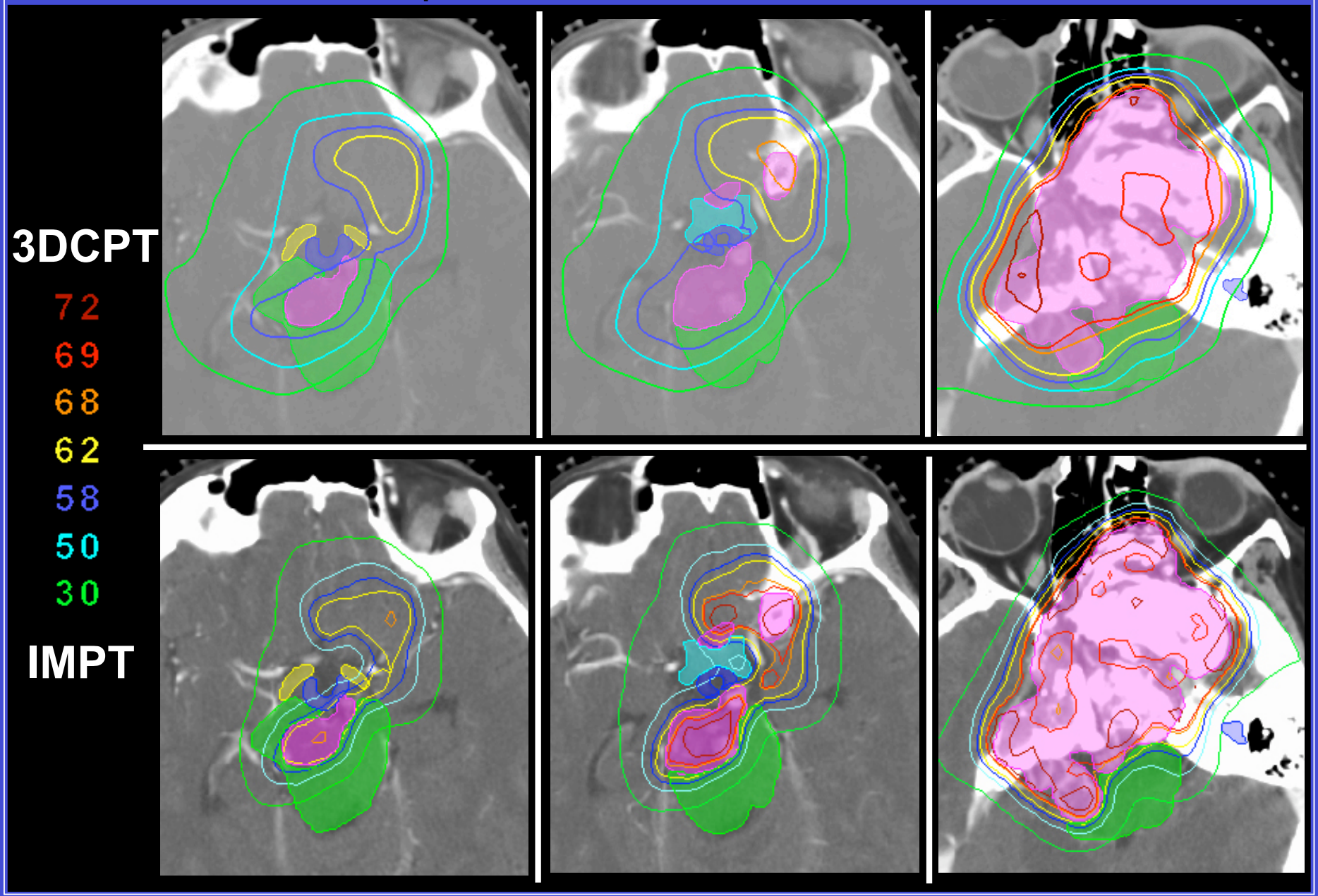

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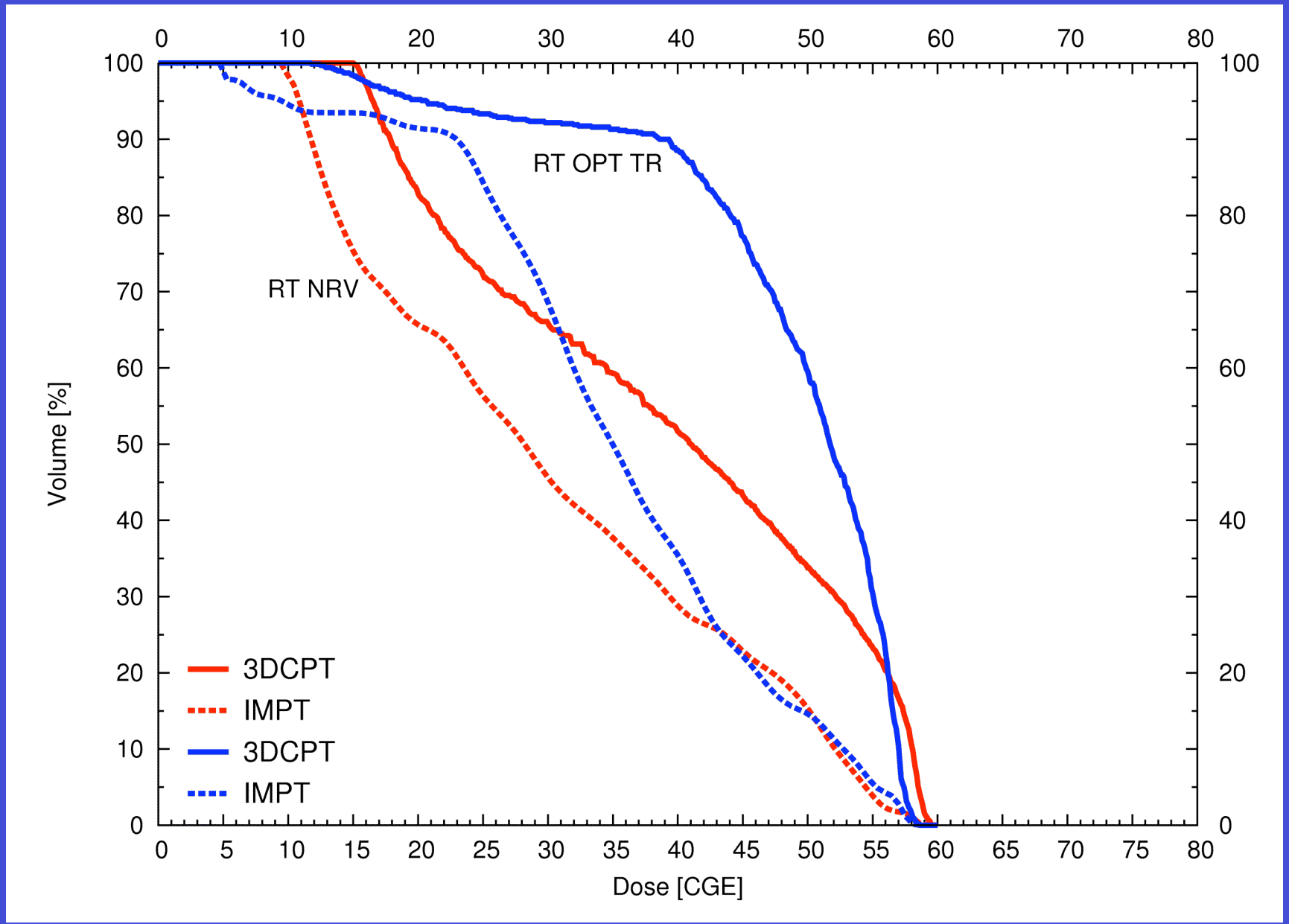

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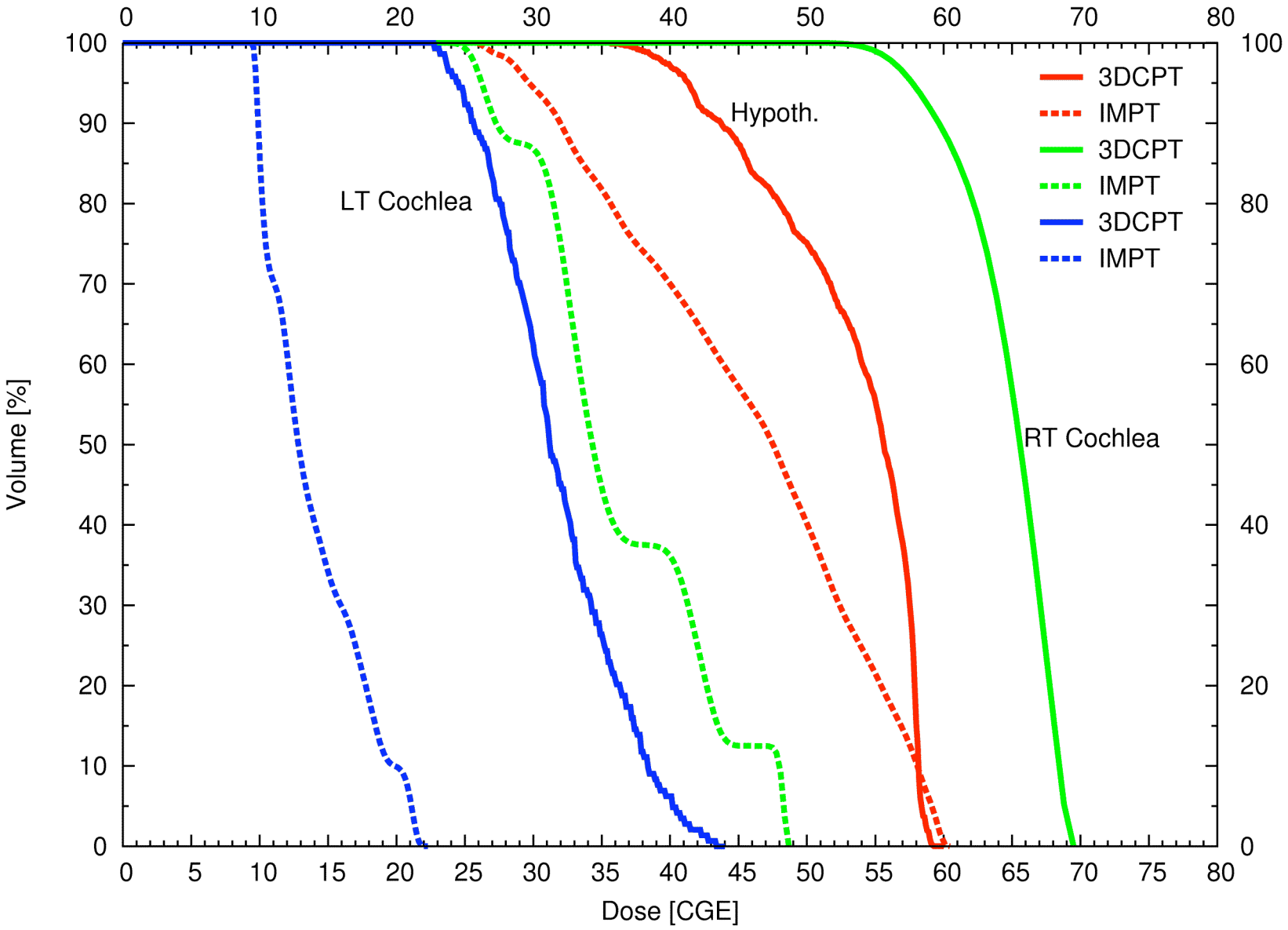
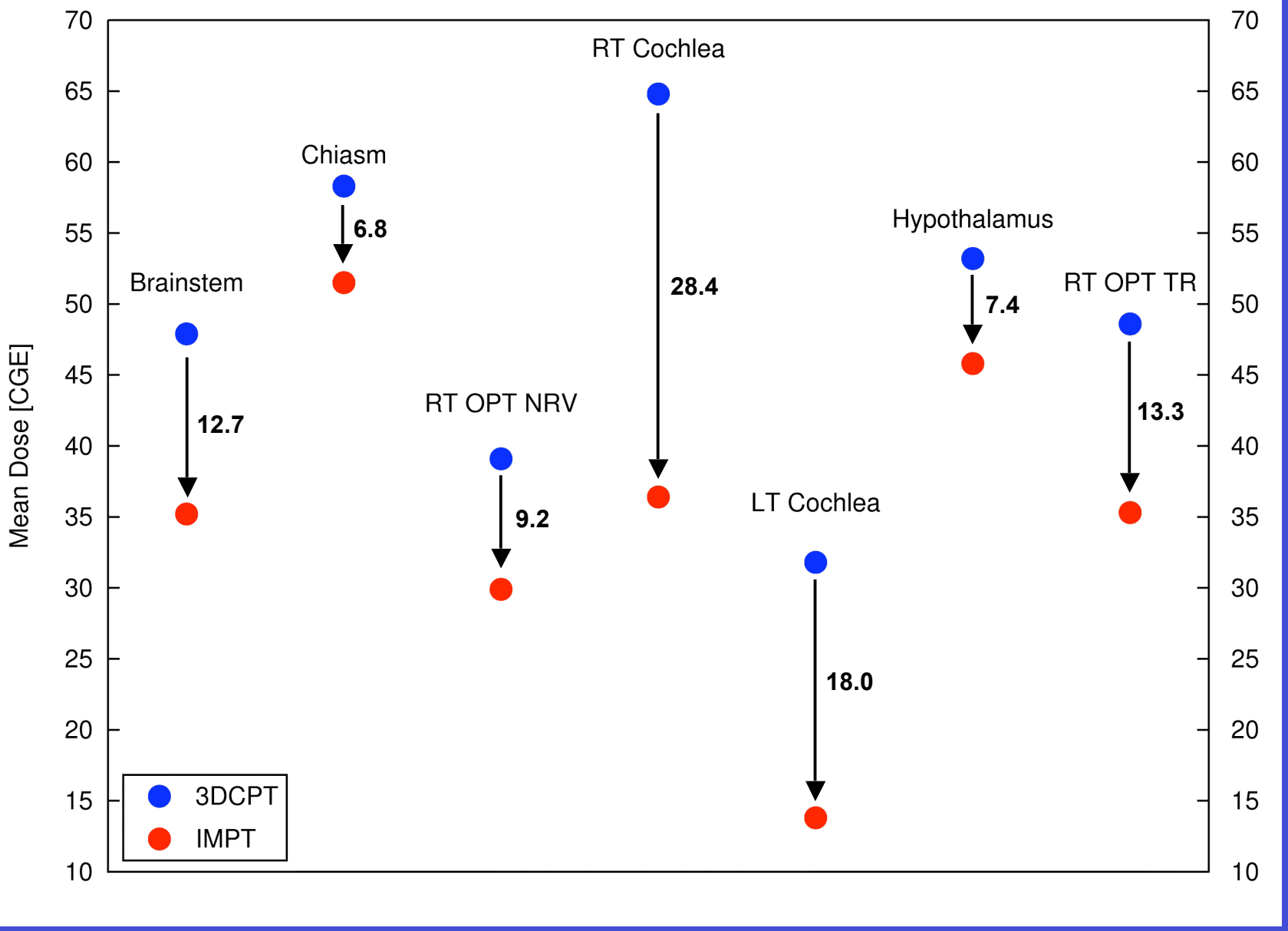
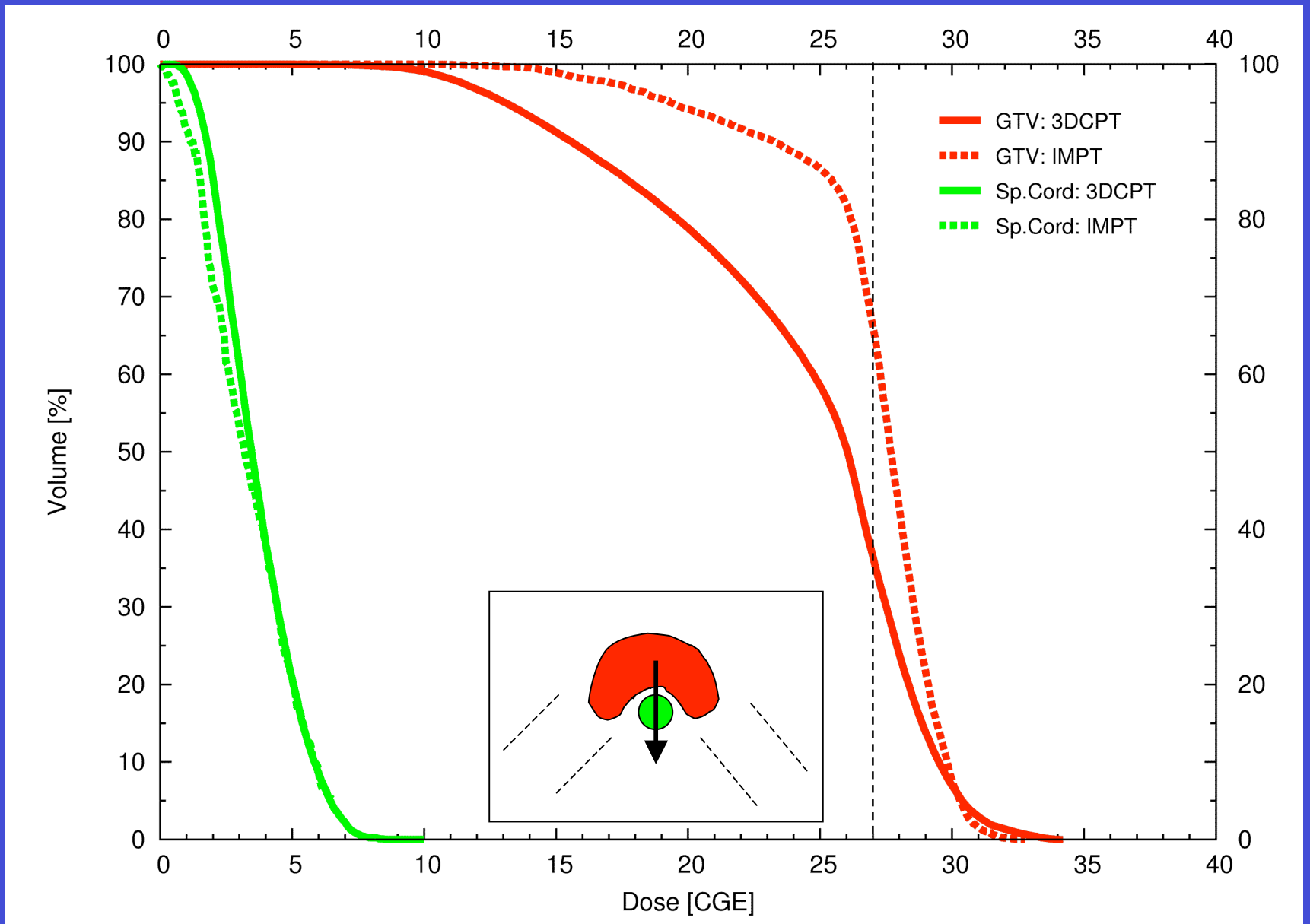


2nd Clinical example: the mean dose to OAR



IMPT and 3DCPT under setup and range errors

Paraspinal case: systematic SETUP error of 1 mm



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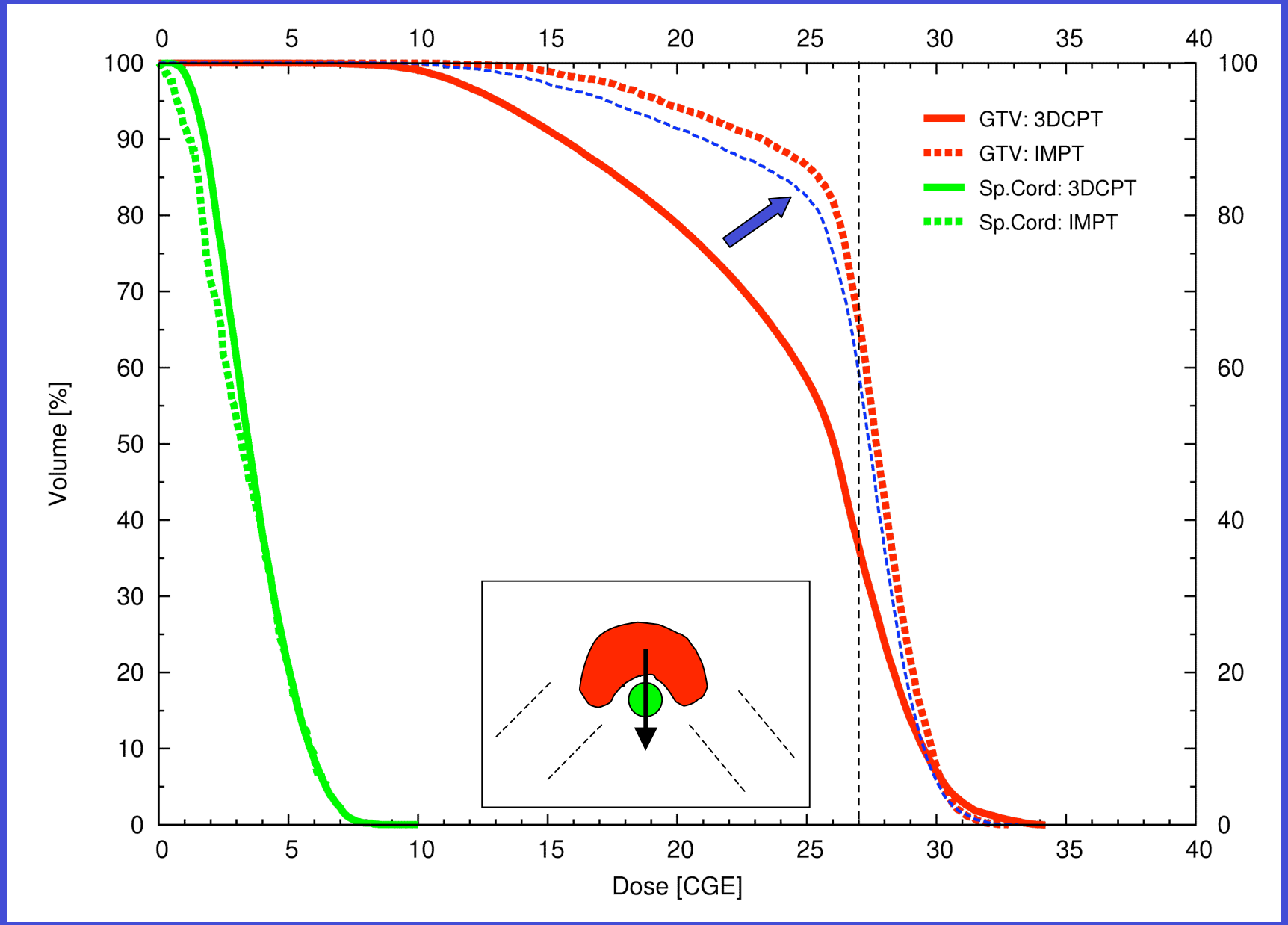

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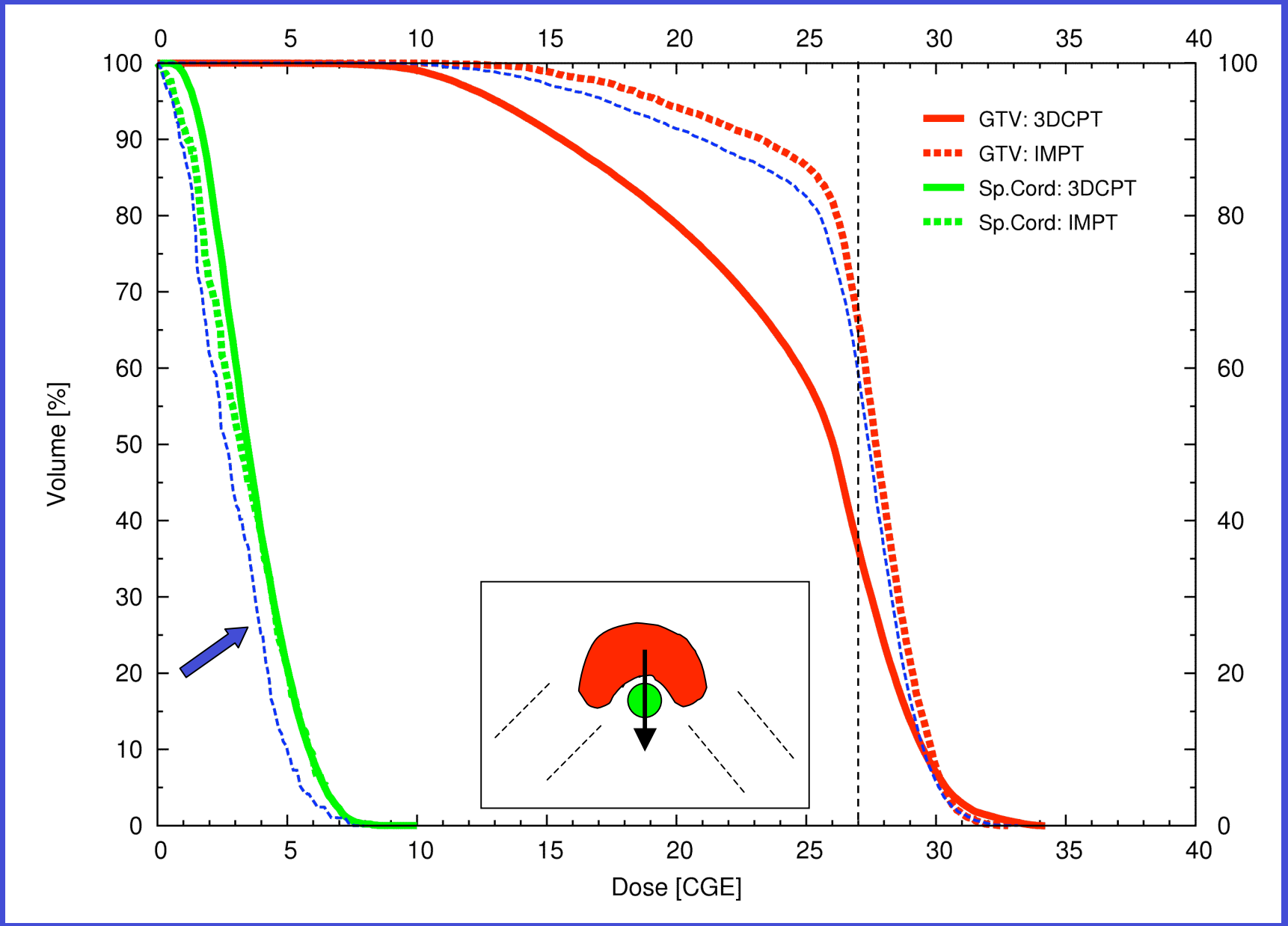

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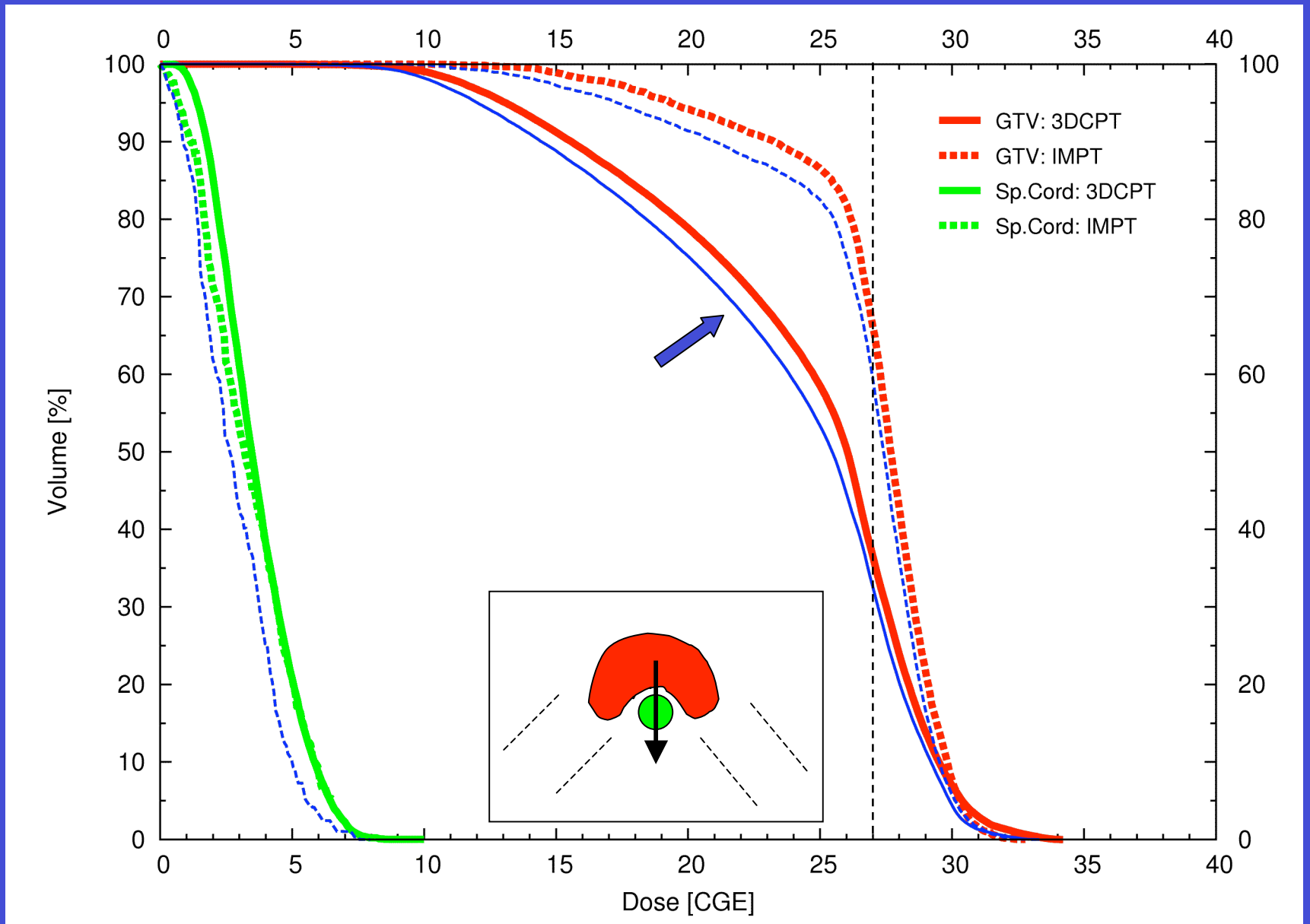

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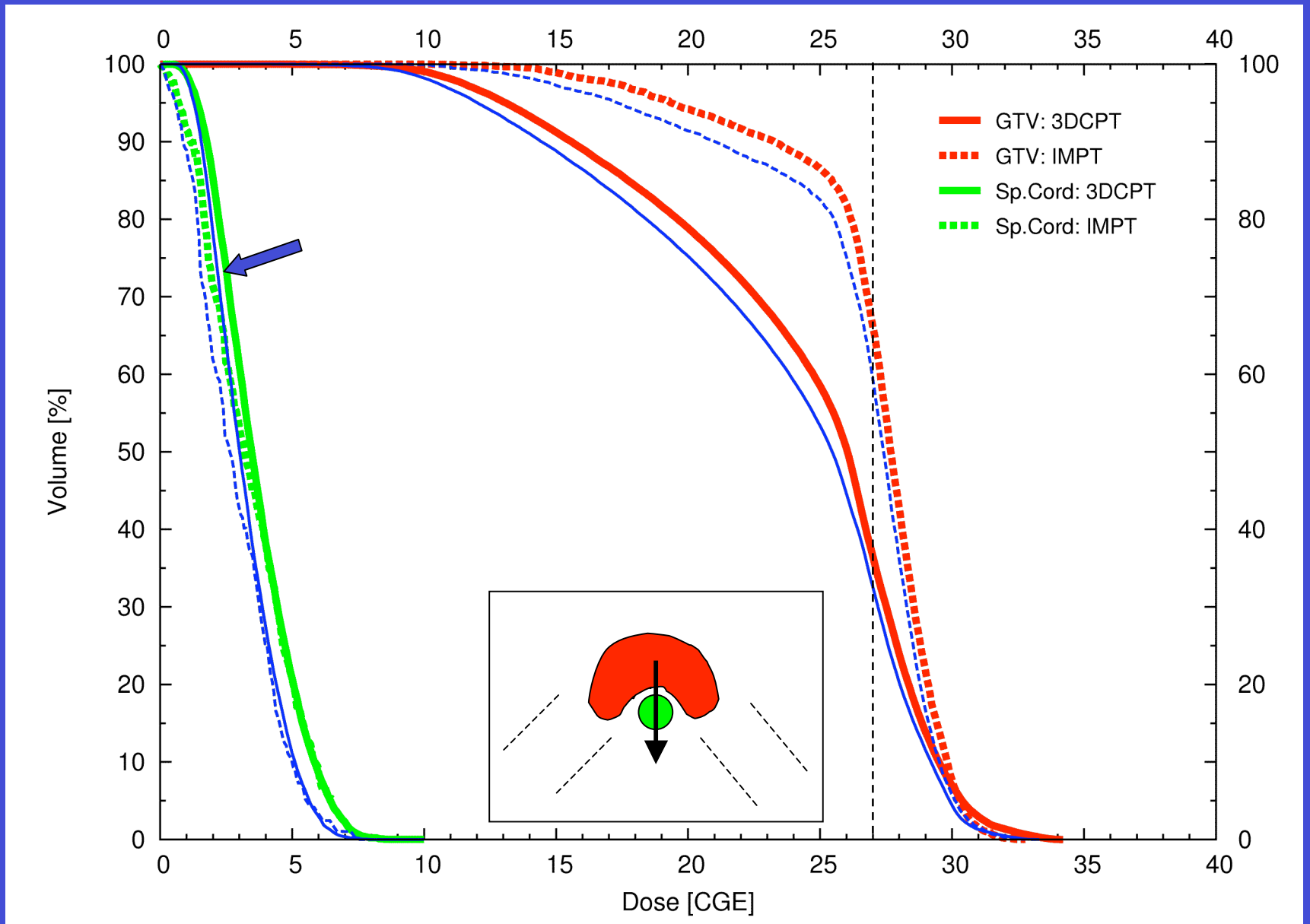

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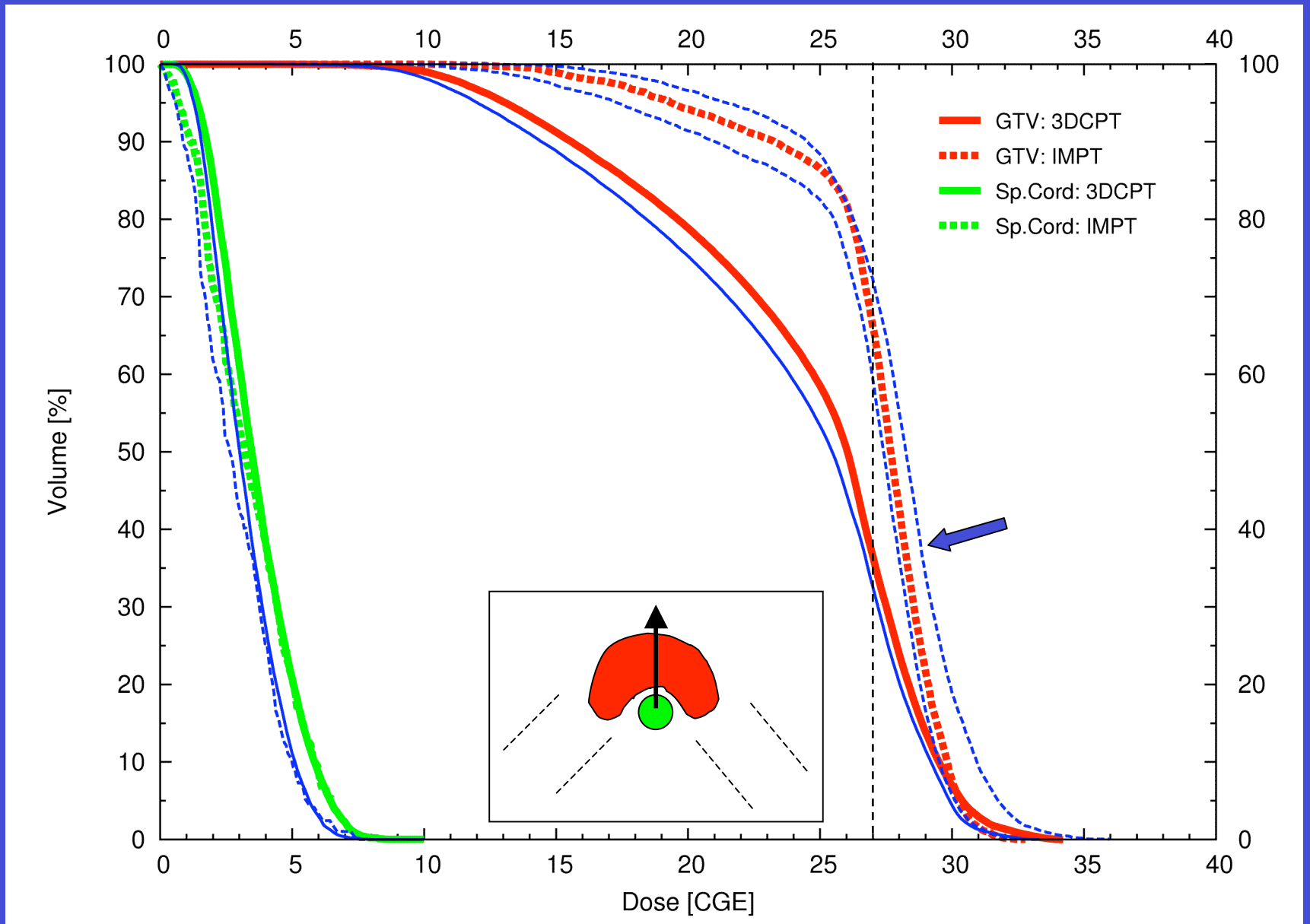

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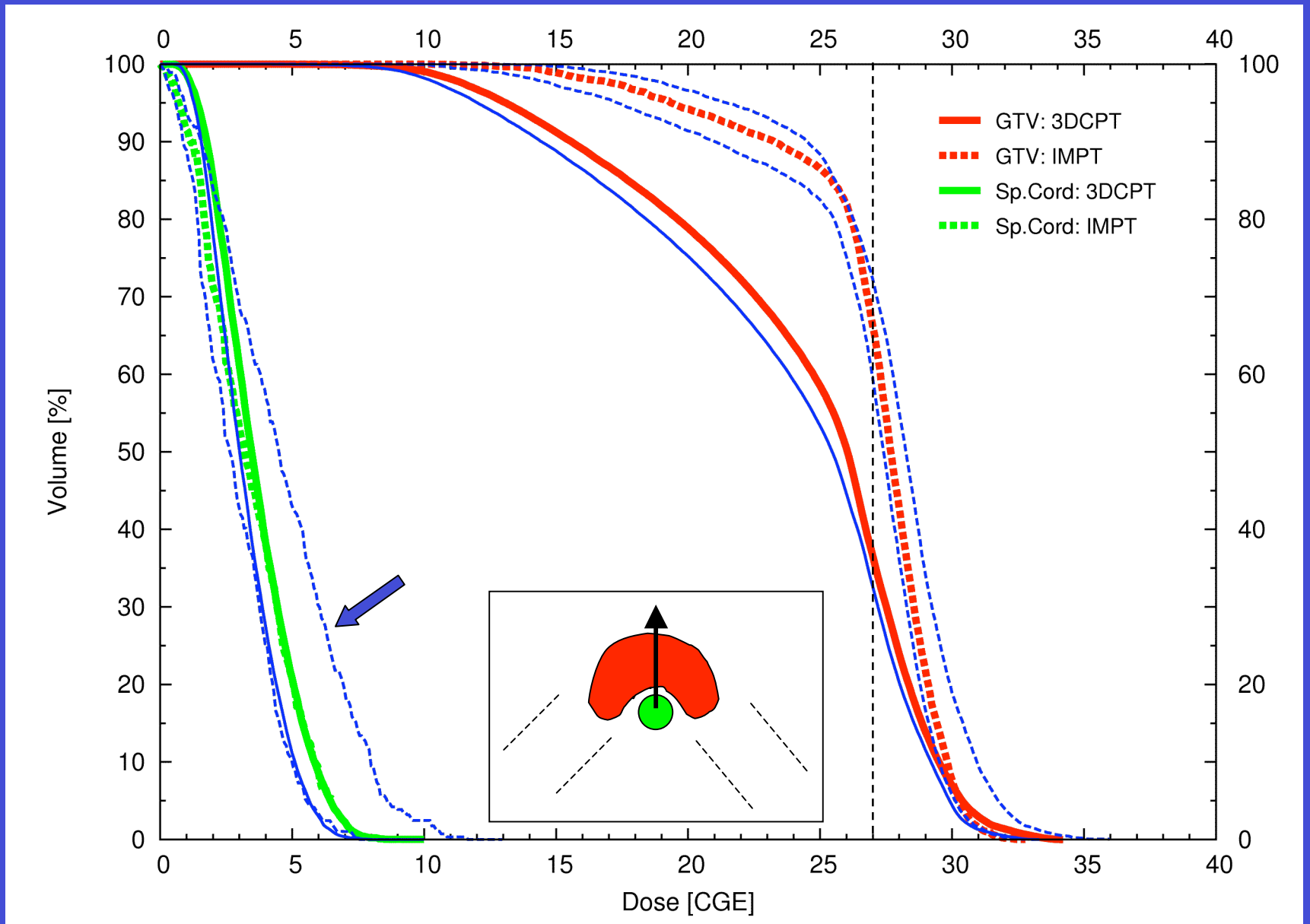

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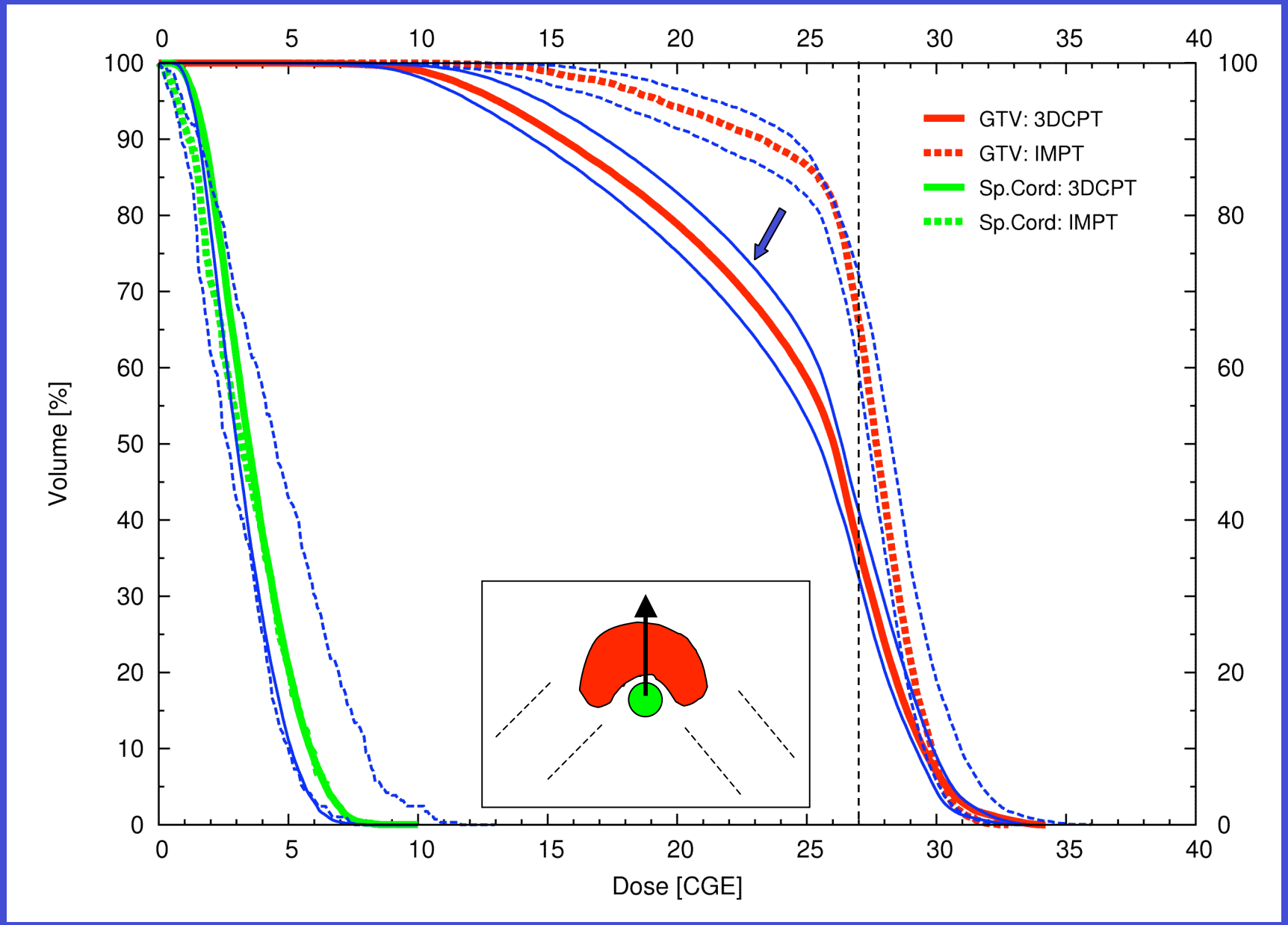

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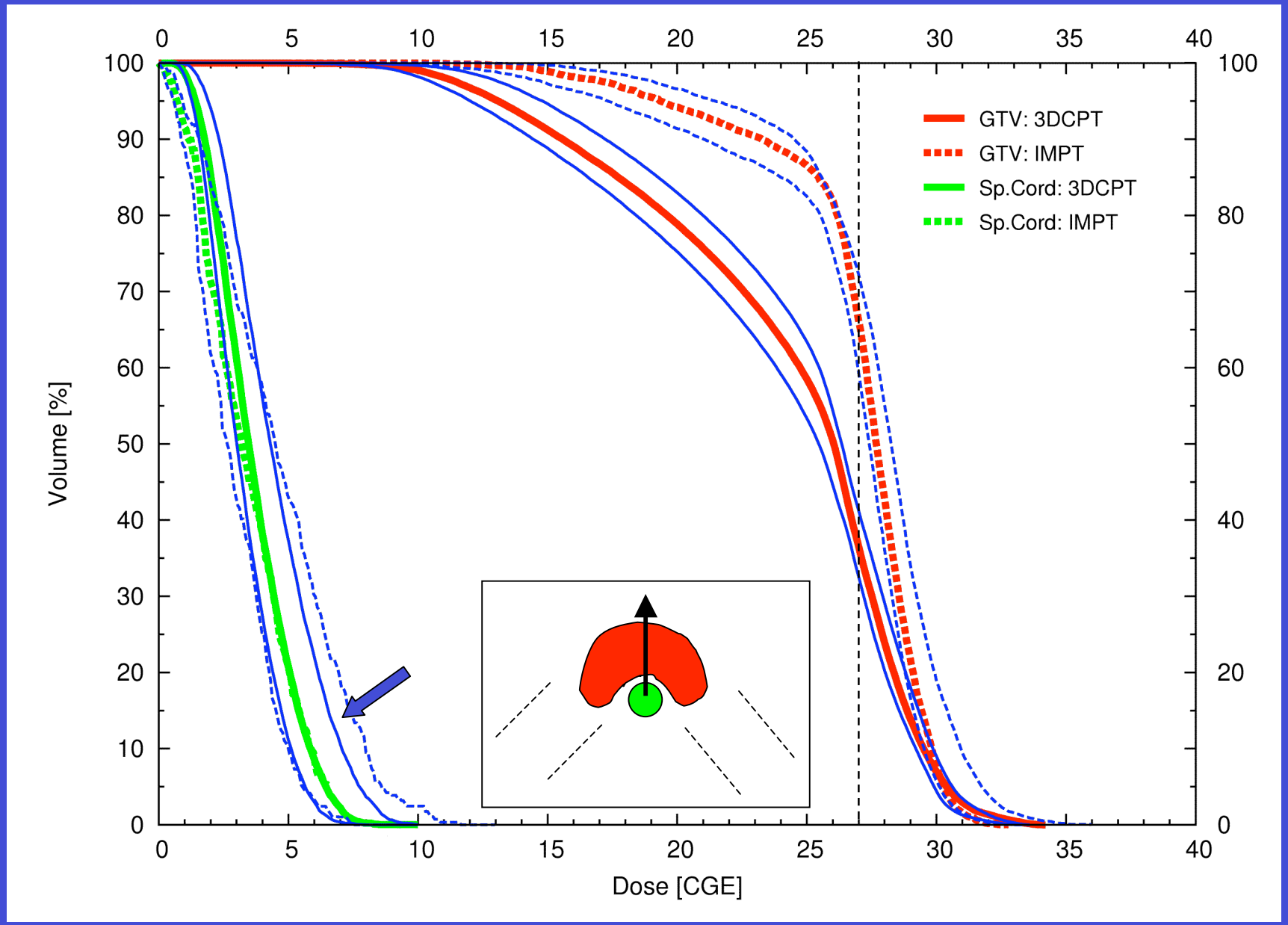
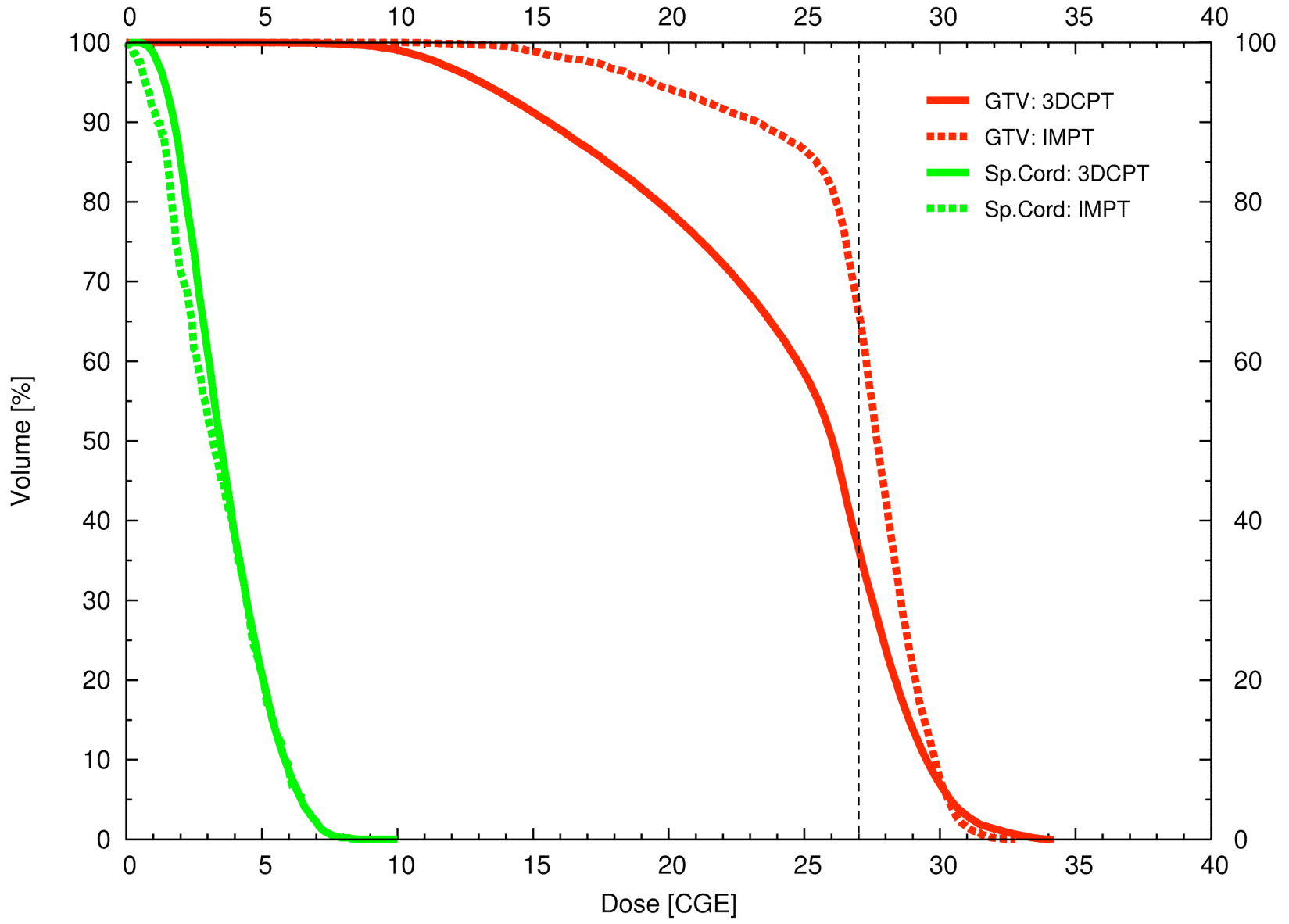


Paraspinal case: systematic RANGE error of 2.5 mm



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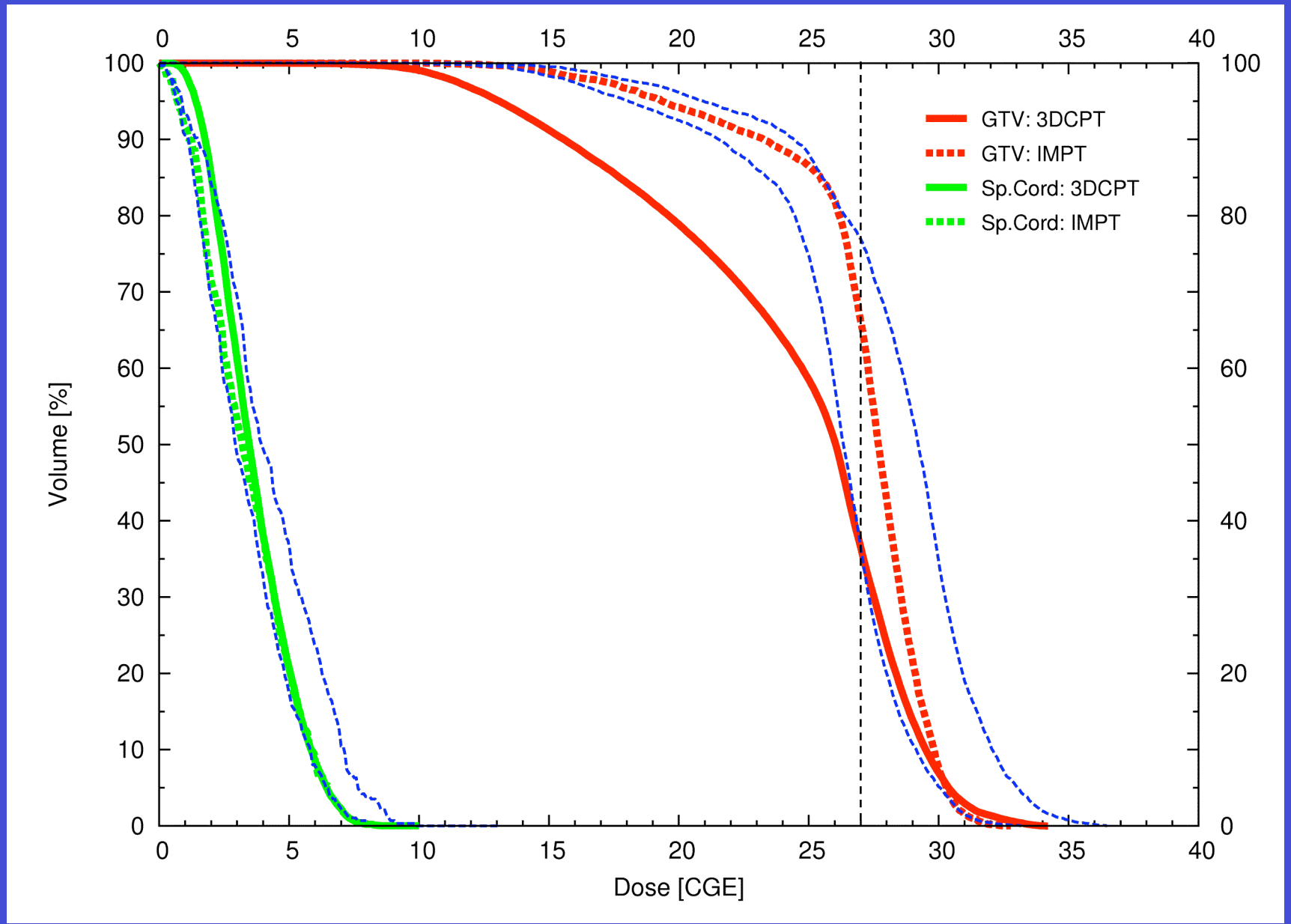

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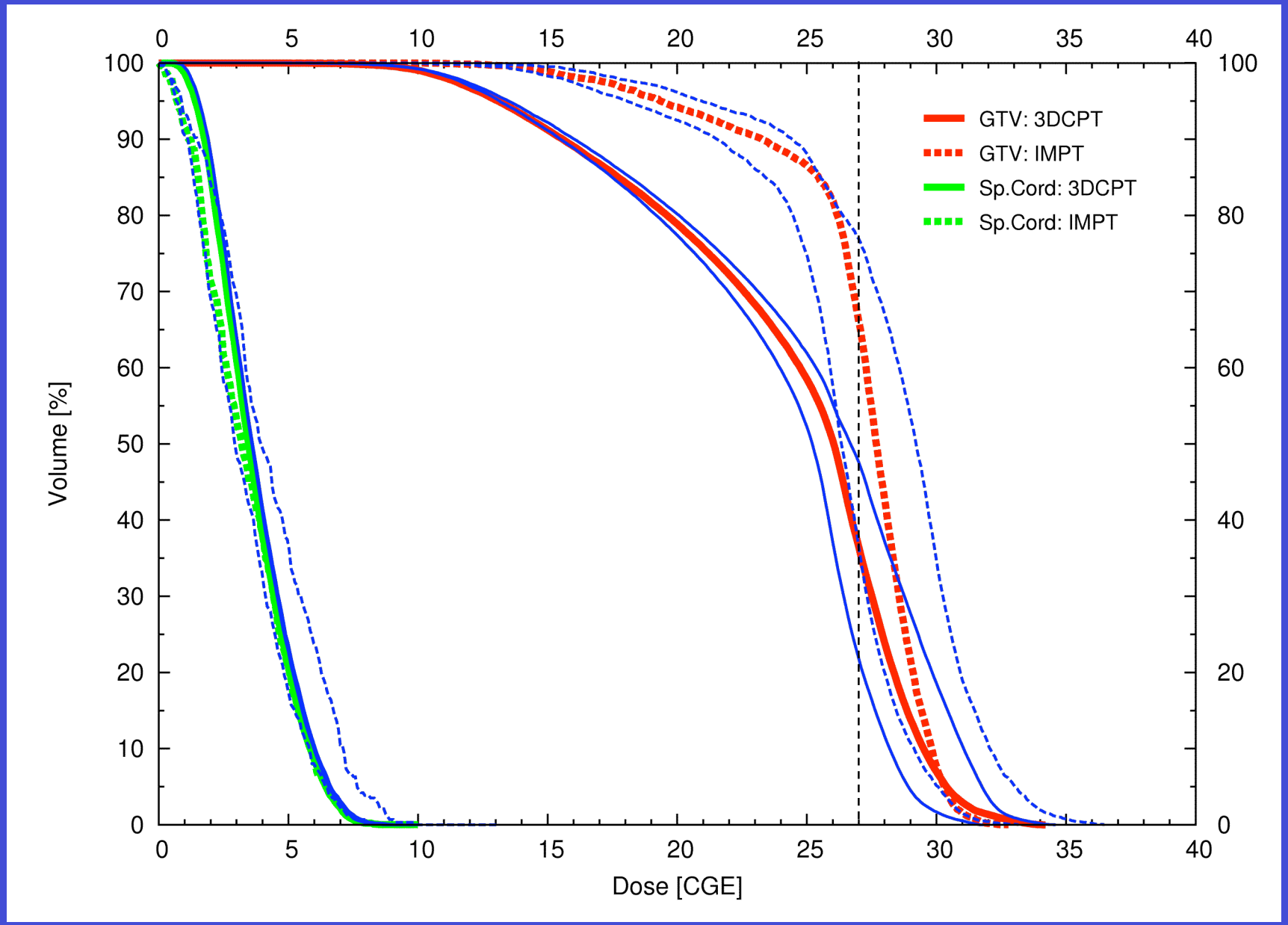


Conclusions for boost with Patching vs. IMPT

Target under setup and range errors

- Significant changes in target coverage
- Similar changes in target coverage for both modalities
- IMPT remains superior

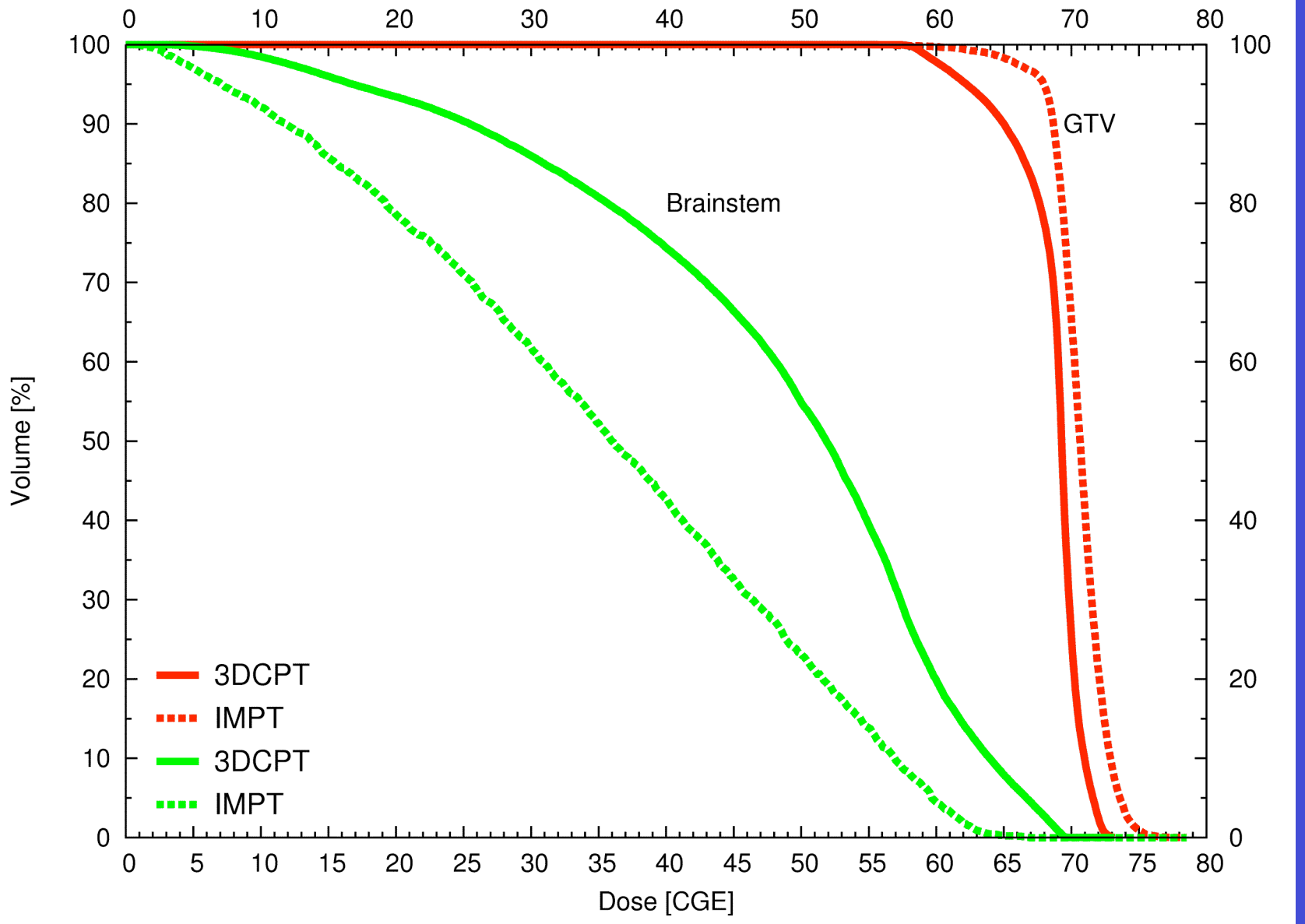
OAR under setup and range errors

- Setup errors are more critical than range errors
- Dose more likely to exceed tolerances when using IMPT
- 3DCPT insensitive to range errors

Solution

- Assure patient positioning
- Add margin to OAR (PRV)

Skull-base case: systematic SETUP error of 1 mm



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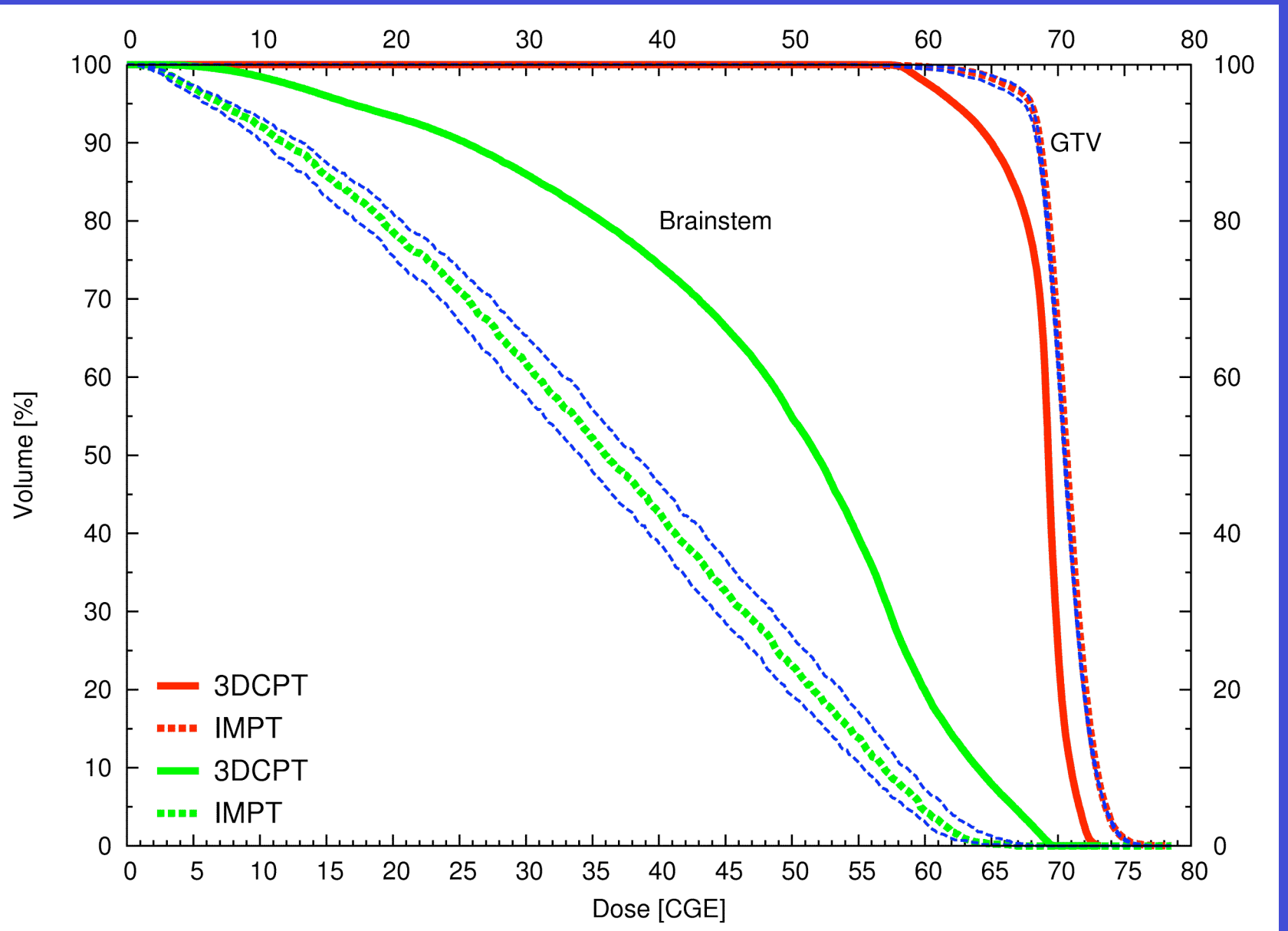

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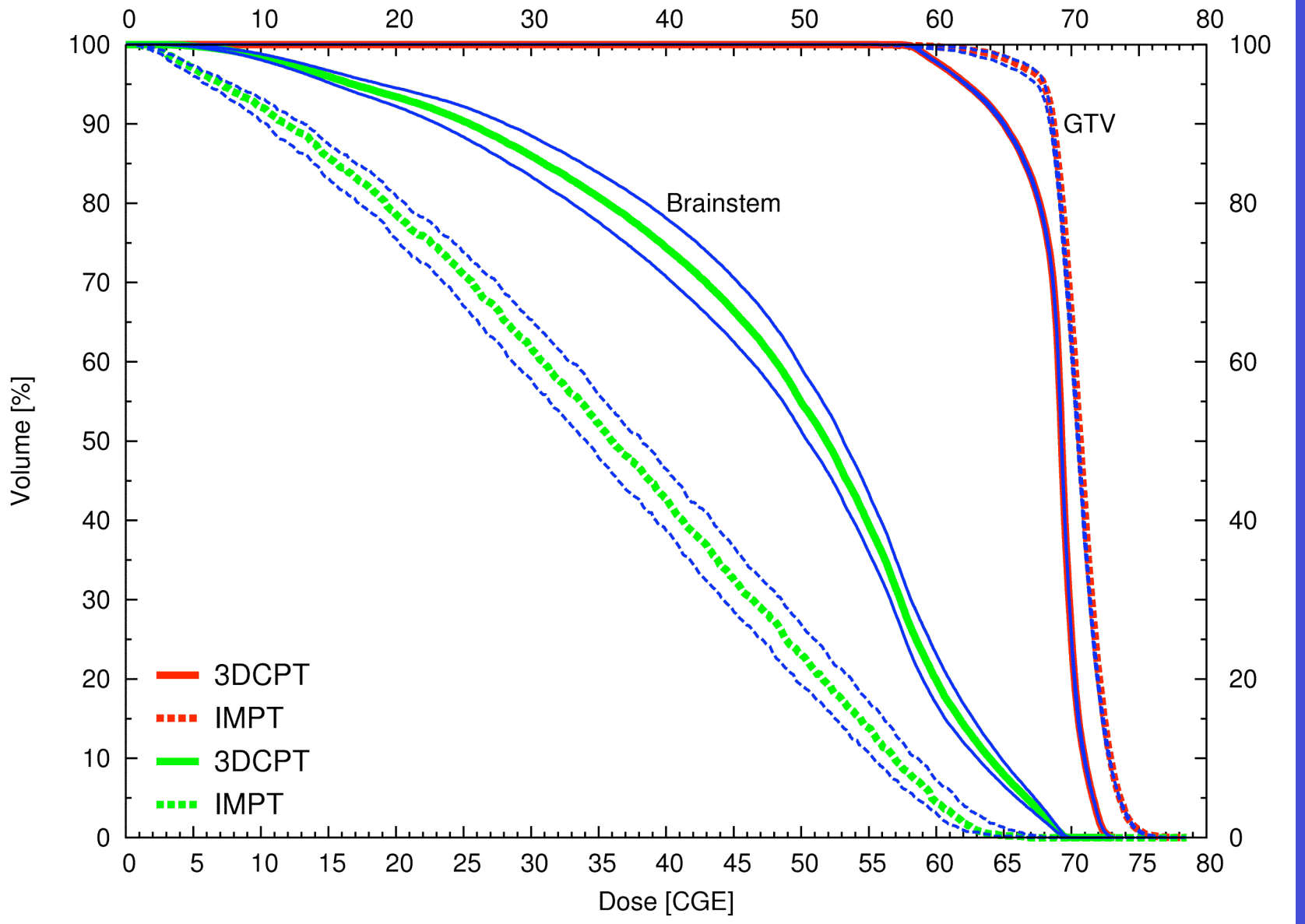

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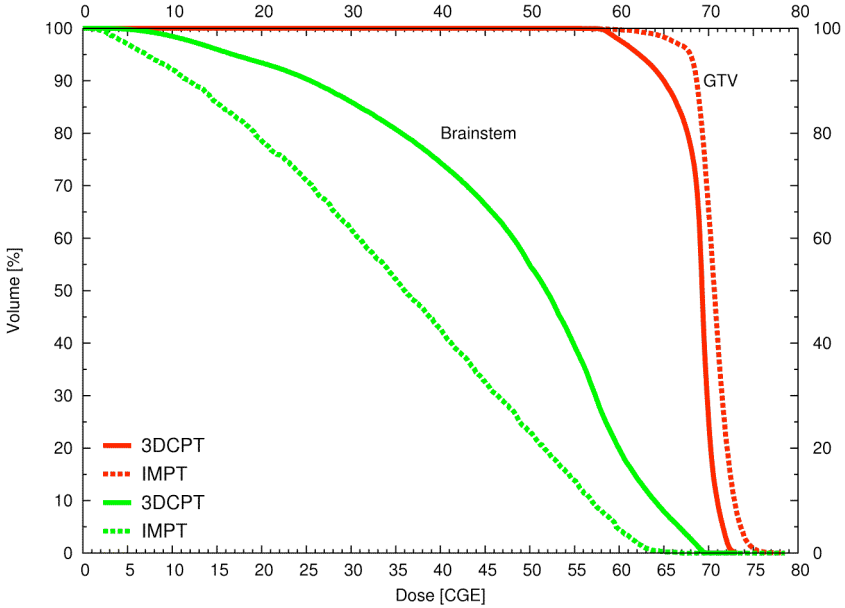

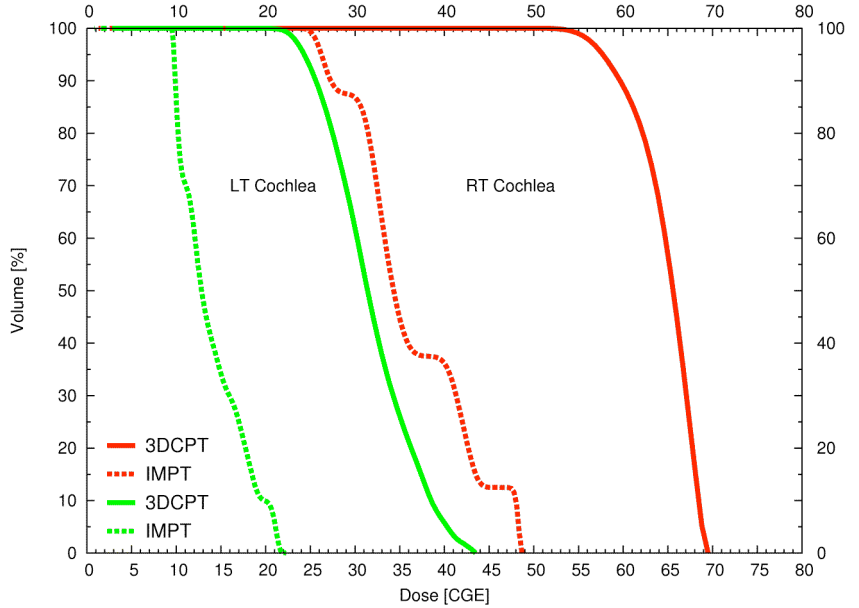

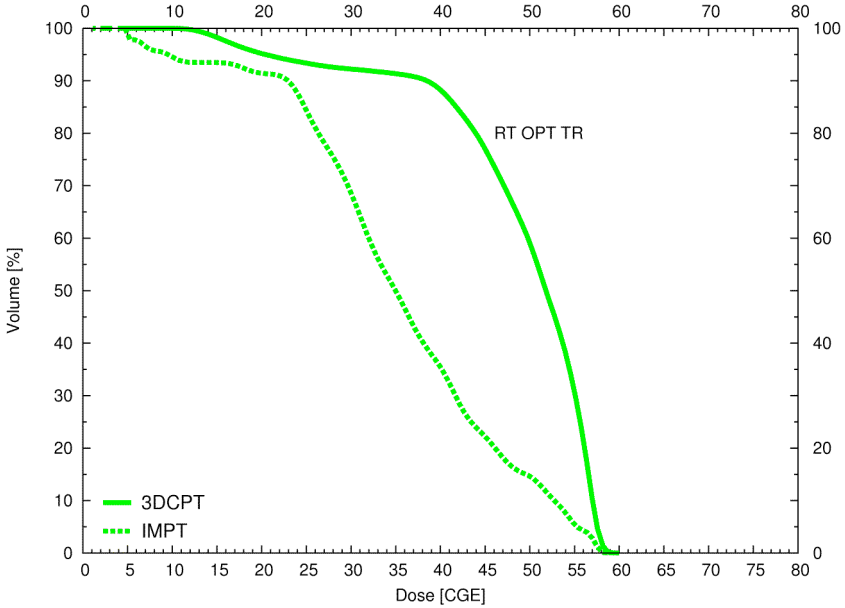

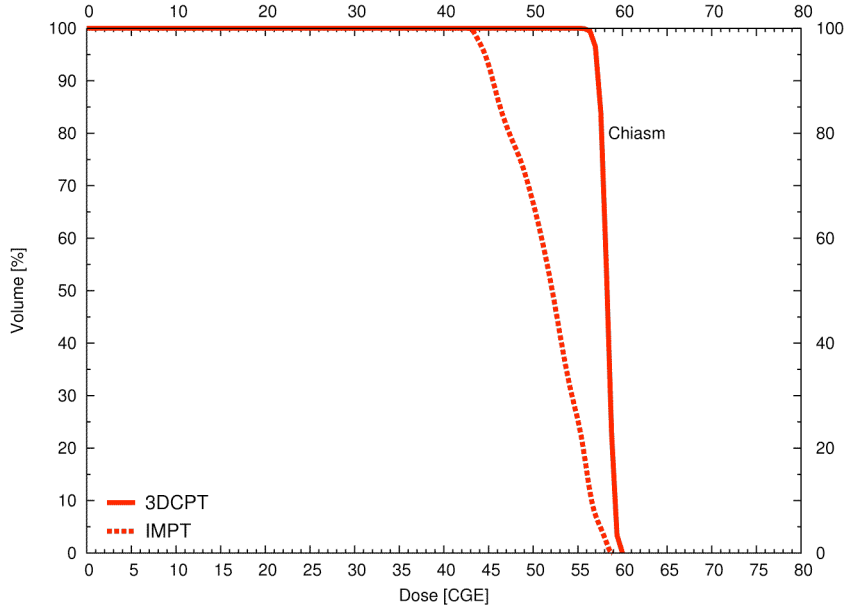

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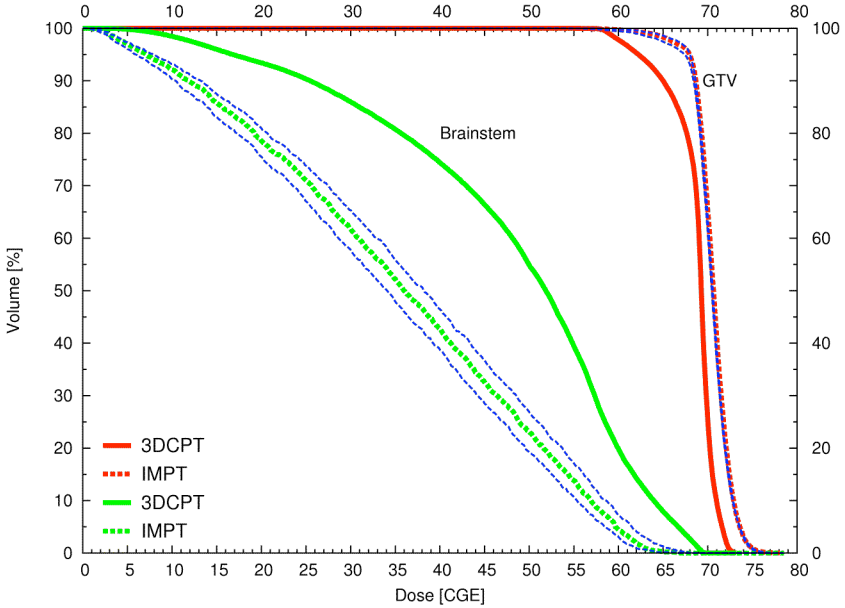

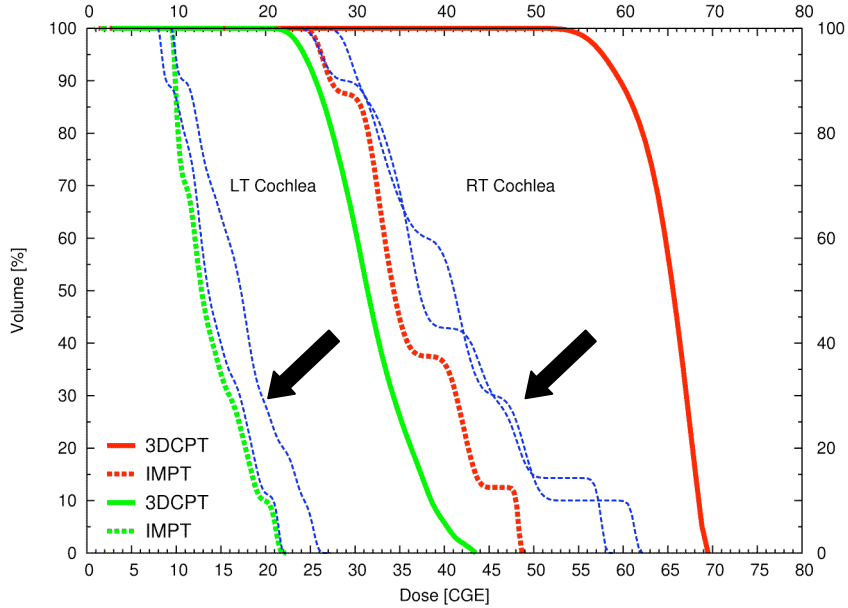

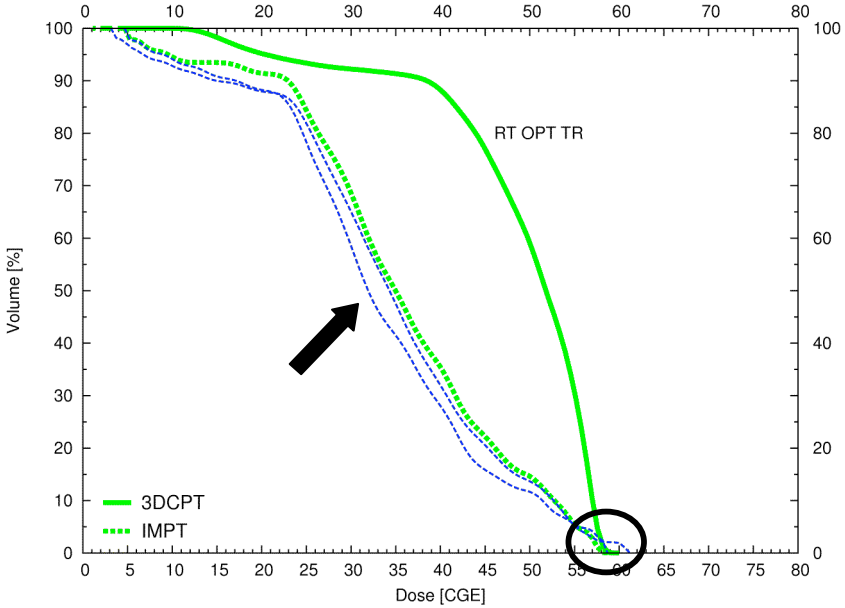

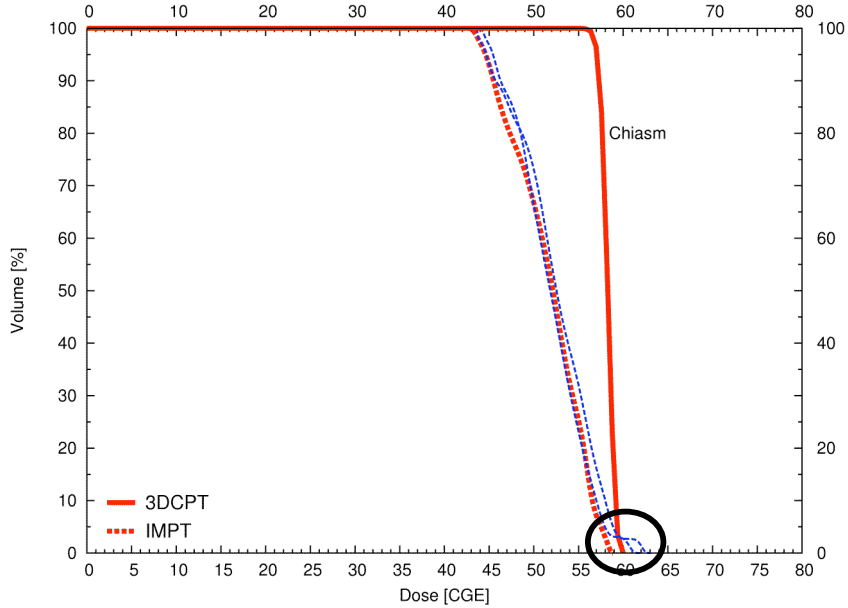

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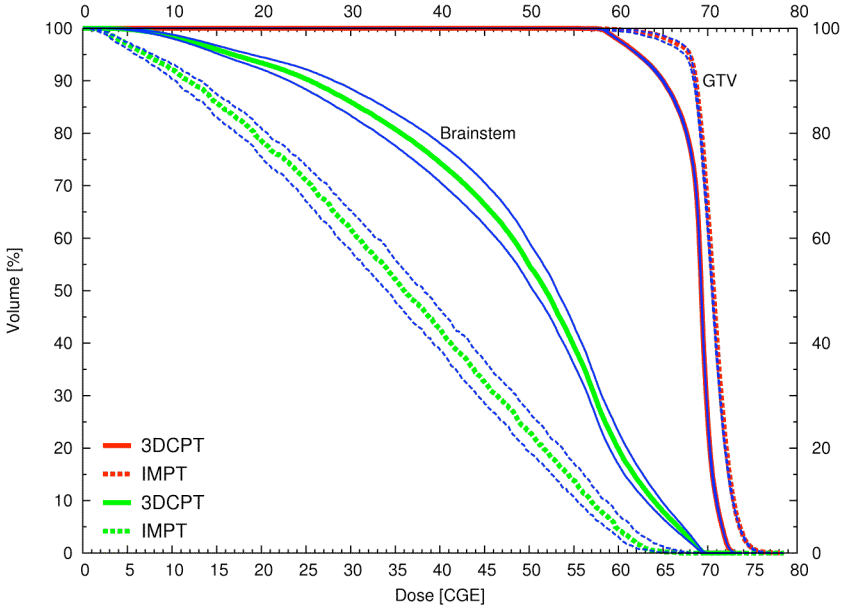
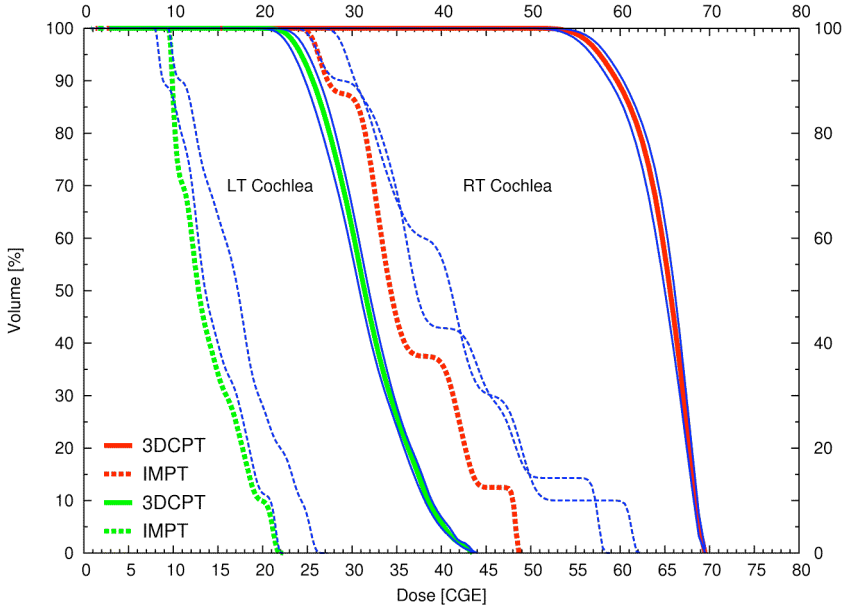
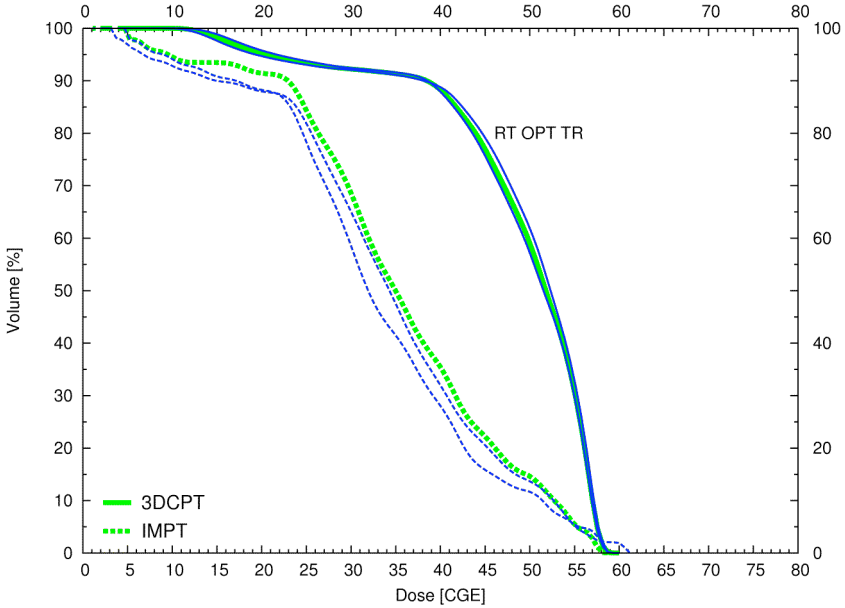
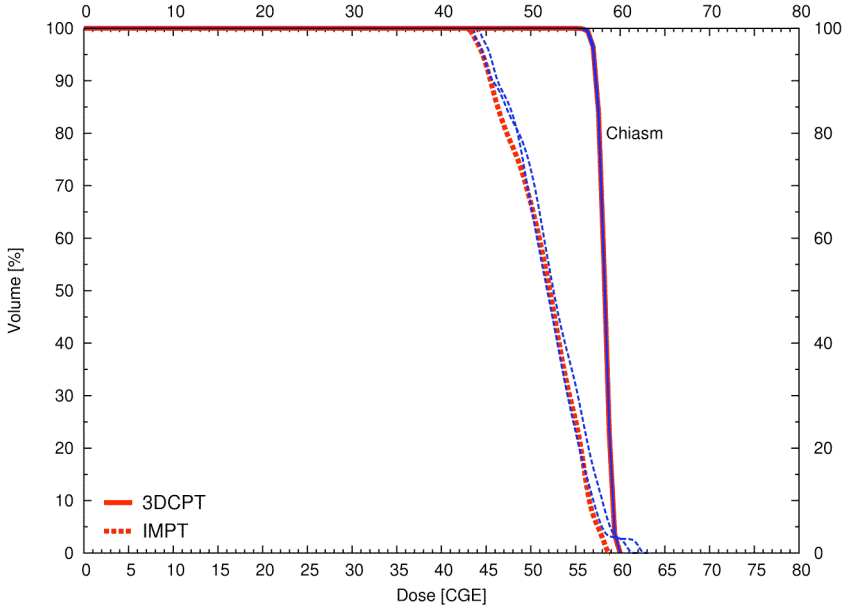
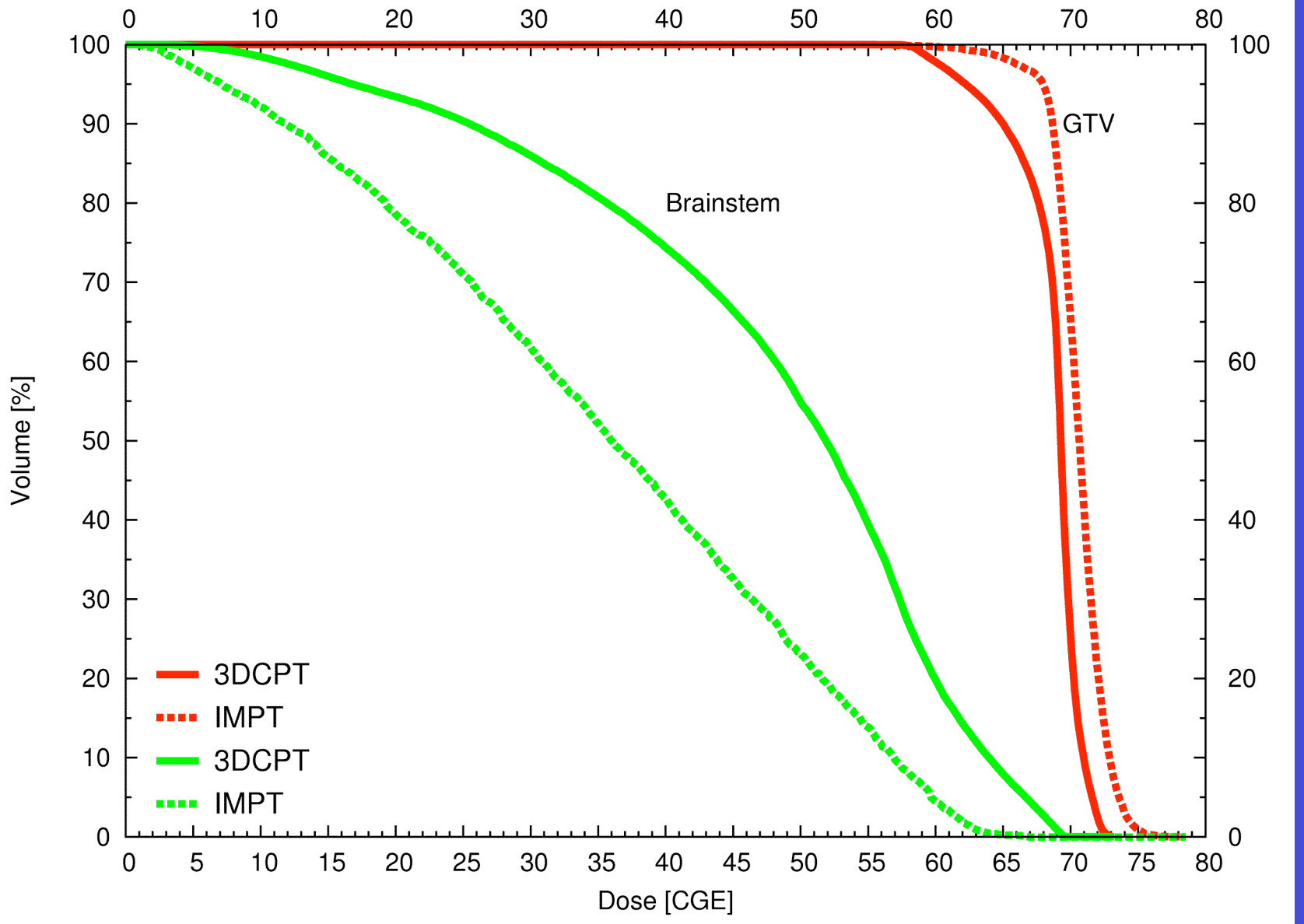








Skull-base case: systematic RANGE error of 2.5 mm



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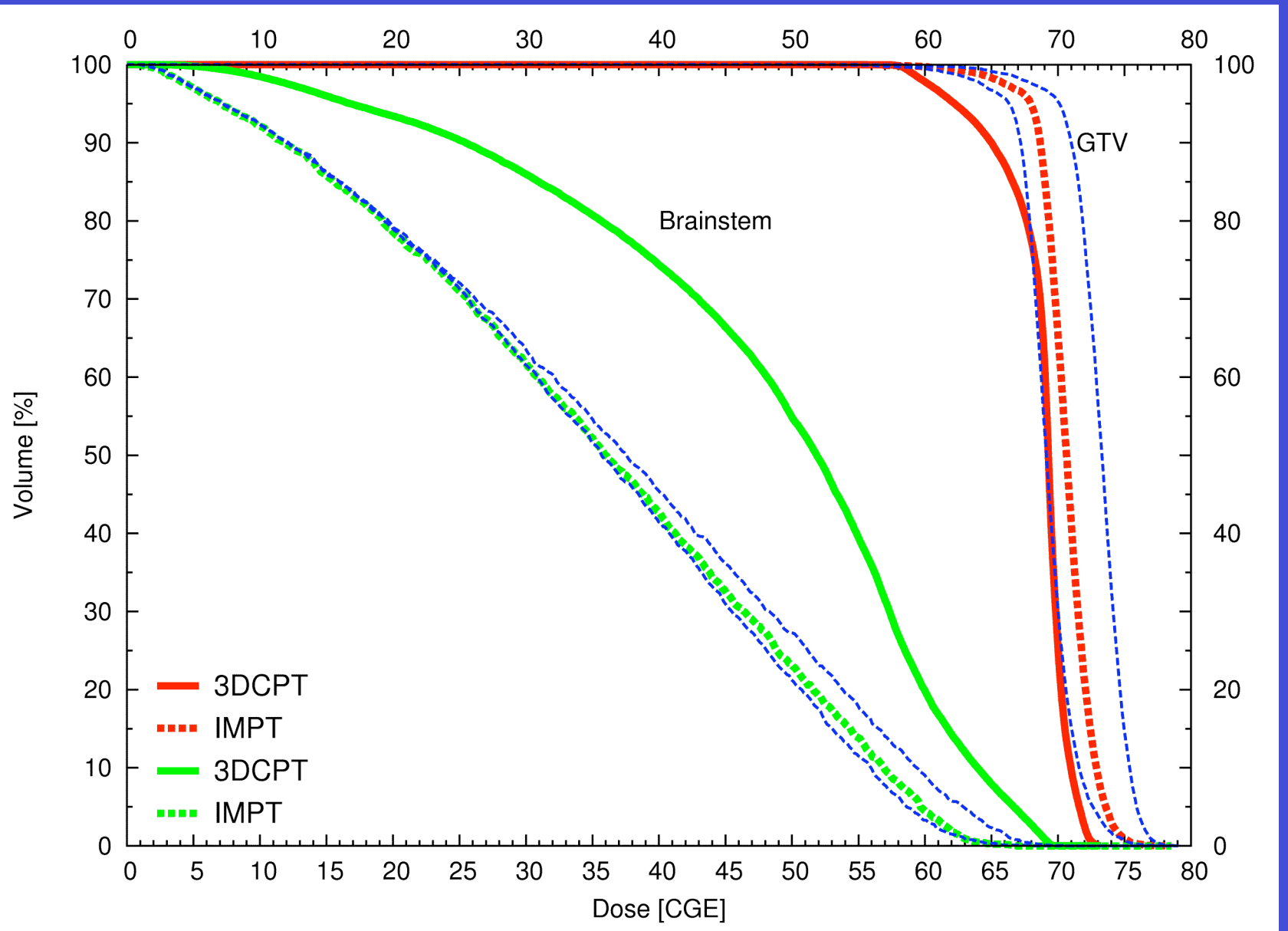

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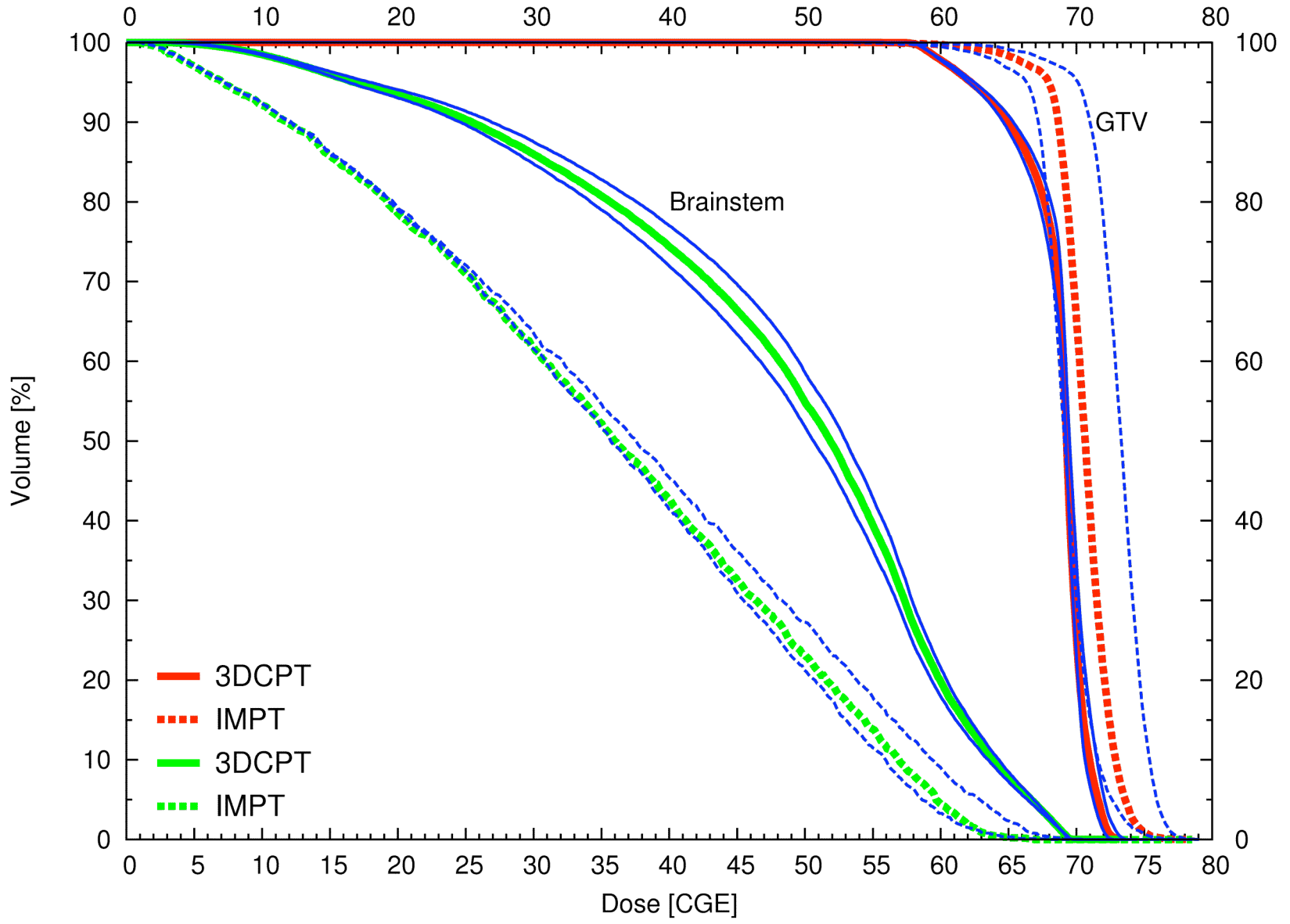

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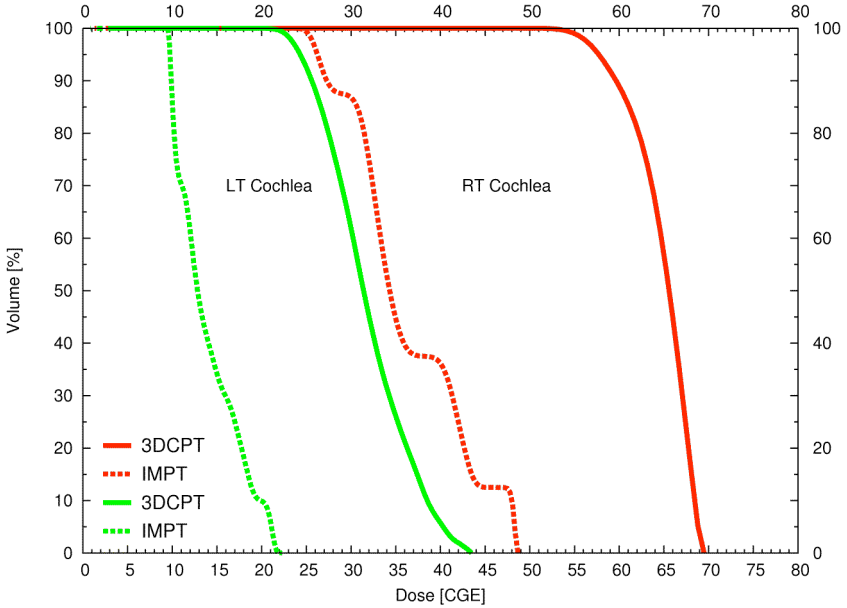

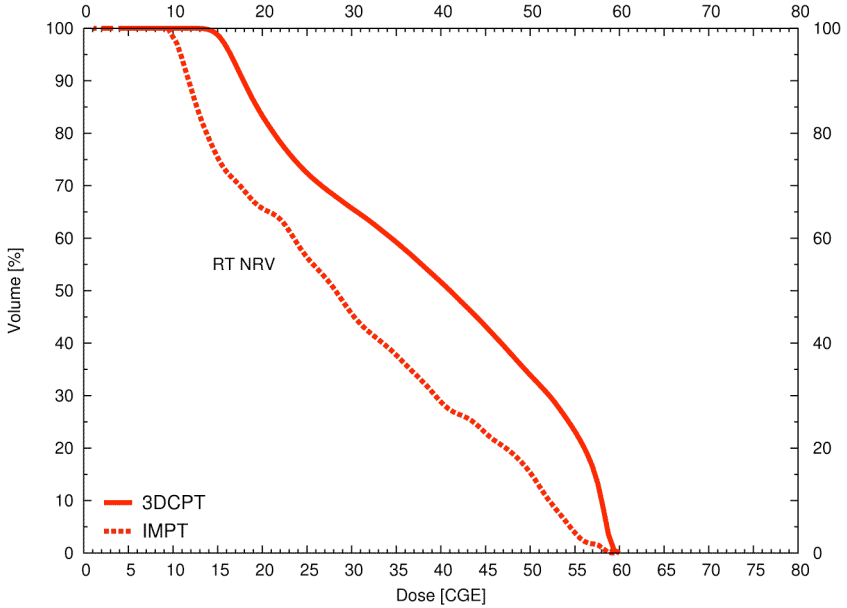

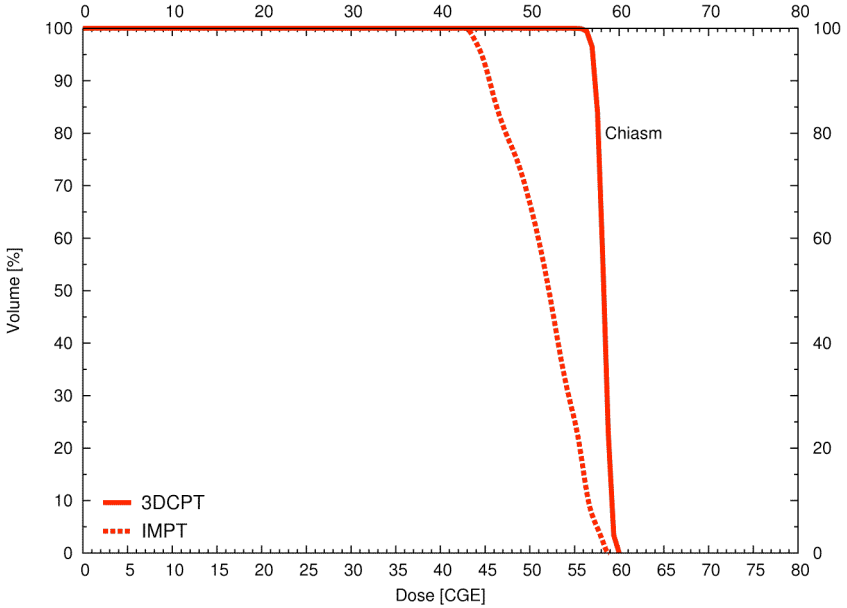

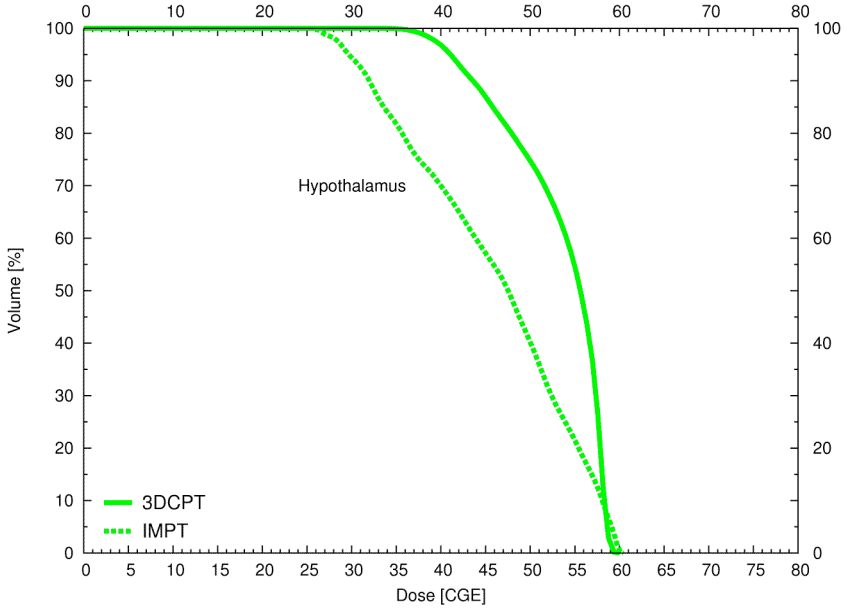

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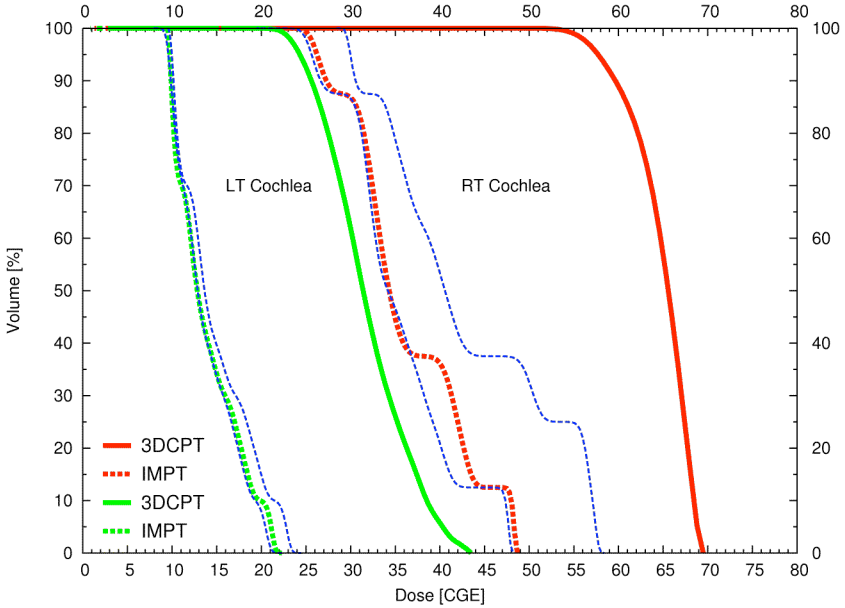

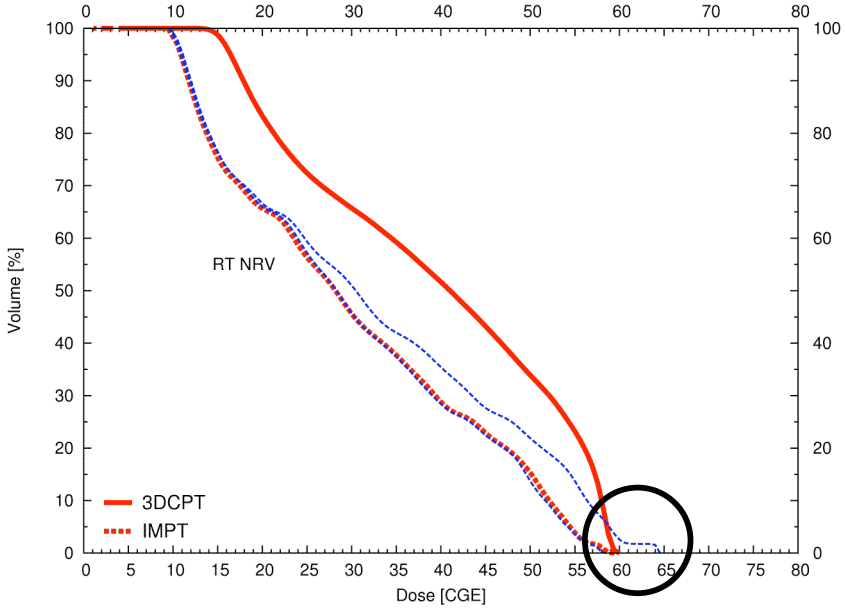

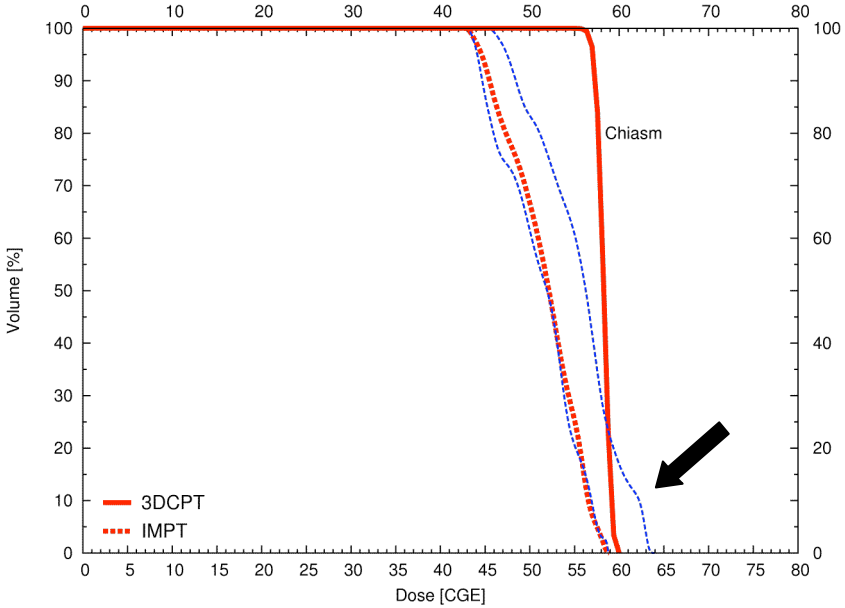

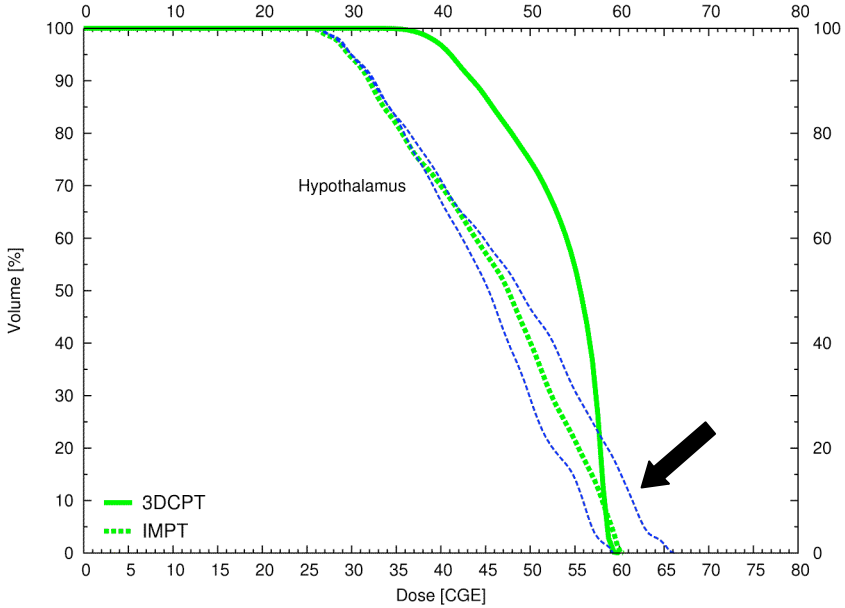

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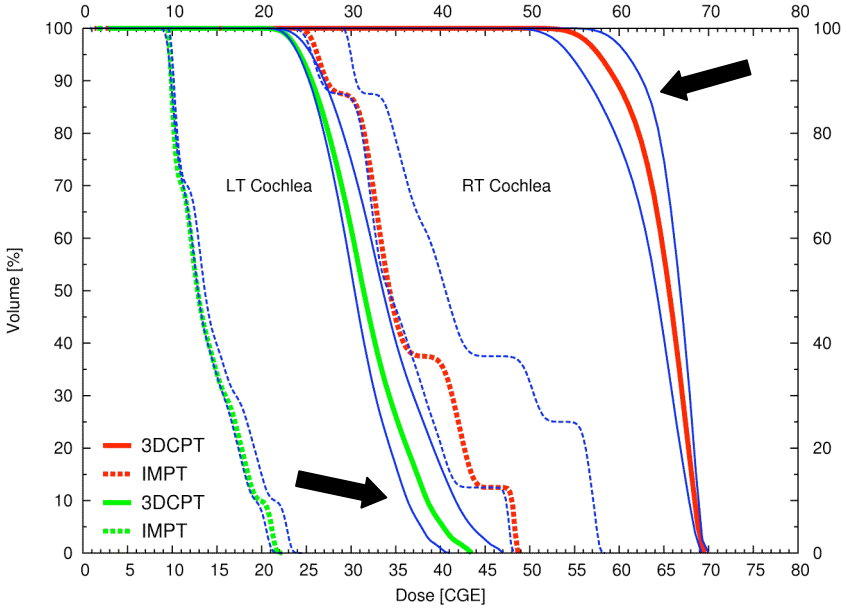
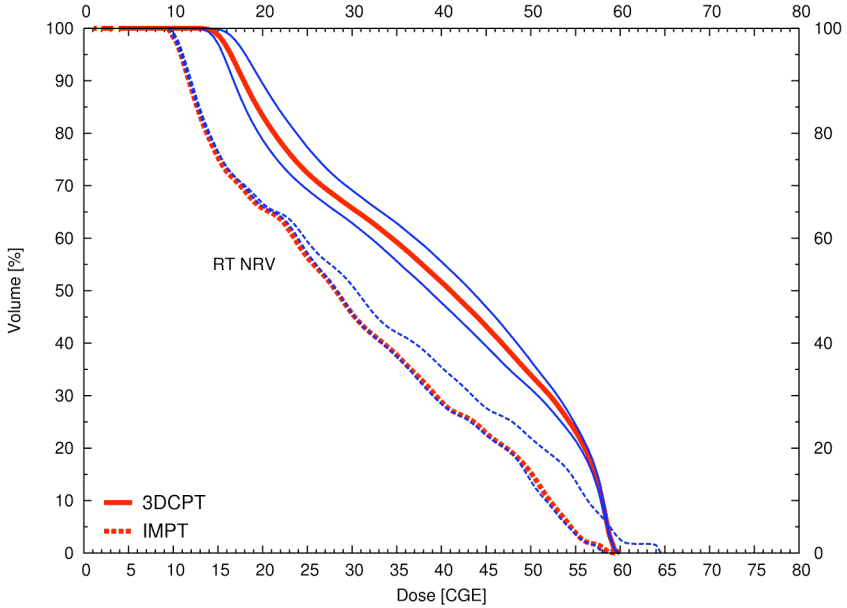
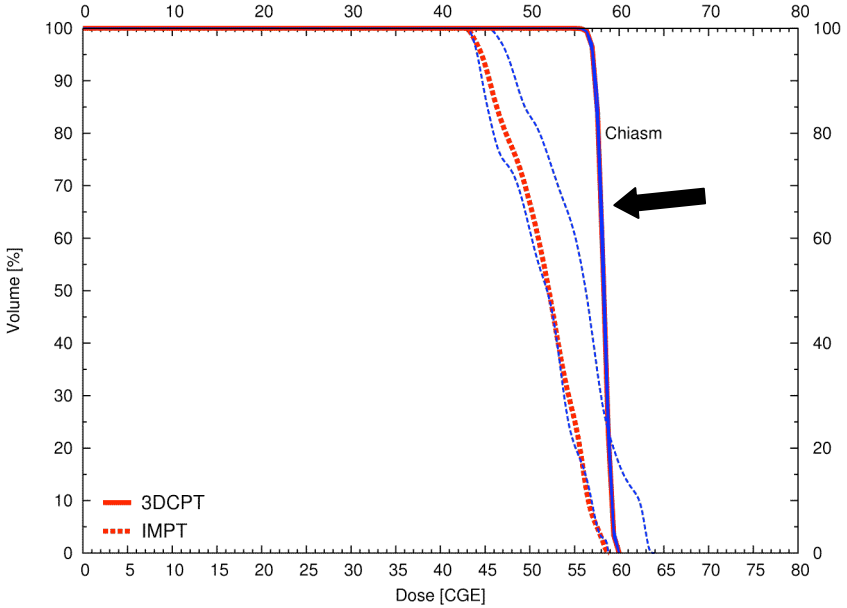
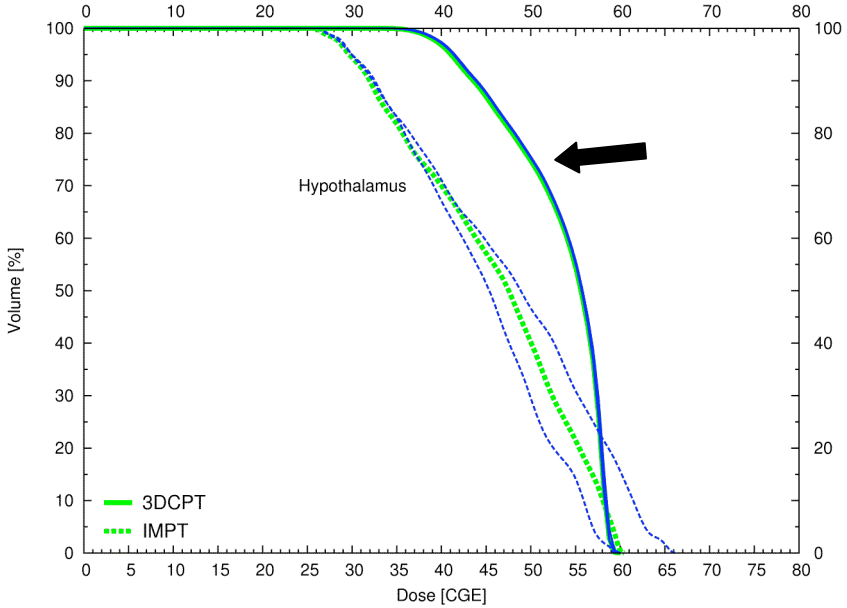
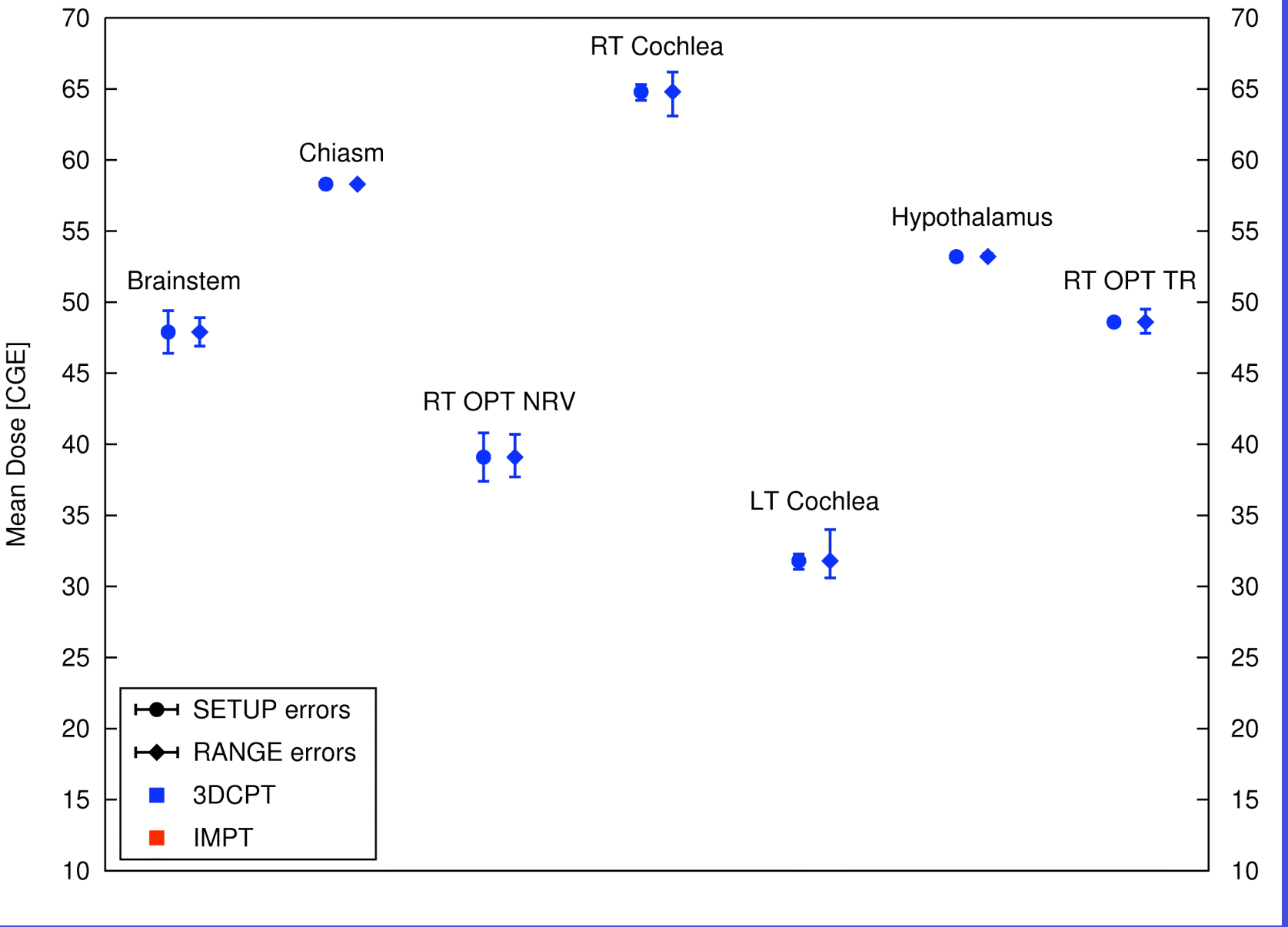








Skull-base case: the mean dose



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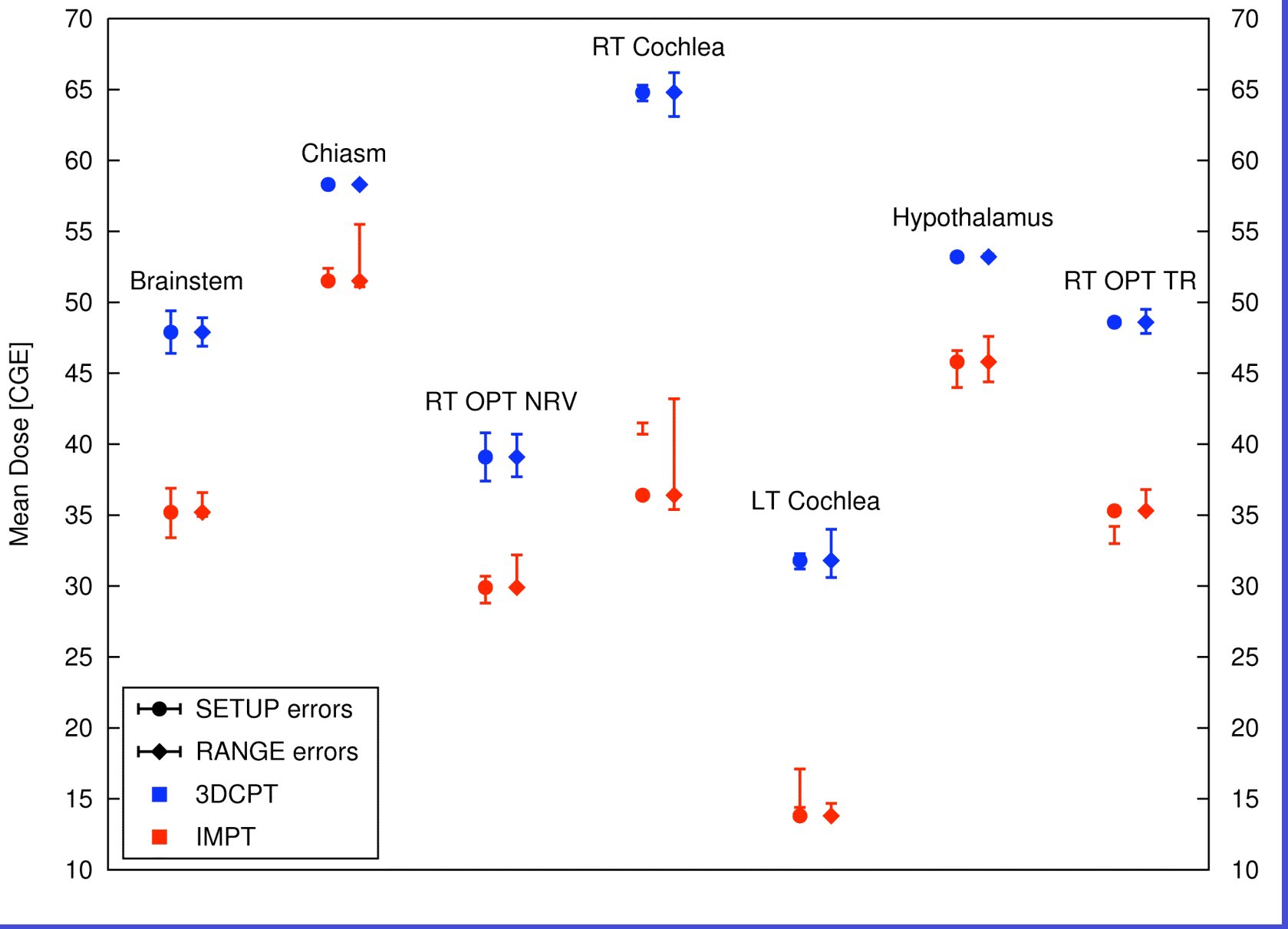

Conclusions for skull-base case

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- Significant changes in target coverage
- Similar changes in target coverage for both modalities
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OAR under setup and range errors

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Conclusions for skull-base case

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- Similar changes in target coverage for both modalities
- IMPT remains superior

OAR under setup and range errors

- Setup errors are more critical than range errors
- Dose more likely to exceed tolerances when using IMPT
- 3DCPT insensitive to range errors

Solution

- Assure patient positioning
- Add margin to OAR (PRV)

Conclusions for skull-base case

Target under setup and range errors

- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
- IMPT remains superior

OAR under setup and range errors

- Setup errors are more critical than range errors
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Conclusions for skull-base case

Target under setup and range errors

- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
- IMPT remains superior

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Conclusions for skull-base case

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- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
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Conclusions for skull-base case

Target under setup and range errors

- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
- IMPT remains superior

OAR under setup and range errors

- Range errors are more critical than setup errors
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Solution

- Assure patient positioning
- Add margin to OAR (PRV)

Conclusions for skull-base case

Target under setup and range errors

- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
- IMPT remains superior

OAR under setup and range errors

- Range errors are more critical than setup errors
- Dose more likely to exceed tolerances when using IMPT under range overshoots
- 3DCPT insensitive to range errors

Solution

- Assure patient positioning
- Add margin to OAR (PRV)

Conclusions for skull-base case

Target under setup and range errors

- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
- IMPT remains superior

OAR under setup and range errors

- Range errors are more critical than setup errors
- Dose more likely to exceed tolerances when using IMPT under range overshoots
- 3DCPT is sensitive to range errors too, but not for all organs (no general trend)

Solution

- Assure patient positioning
- Add margin to OAR (PRV)

Conclusions for skull-base case

Target under setup and range errors

- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
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- Dose more likely to exceed tolerances when using IMPT under range overshoots
- 3DCPT is sensitive to range errors too, but not for all organs (no general trend)
- Under setup errors IMPT remains superior (better spare of OAR)

Solution

- Assure patient positioning
- Add margin to OAR (PRV)

Conclusions for skull-base case

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- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
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Conclusions for skull-base case

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- Larger changes in target coverage for IMPT
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- Range errors are more critical than setup errors
- Dose more likely to exceed tolerances when using IMPT under range overshoots
- 3DCPT is sensitive to range errors too, but not for all organs (no general trend)
- Under setup errors IMPT remains superior (better spare of OAR)
- The benefits of IMPT are questionable under range overshoots

Solution

- Assure patient positioning
- Add margin to OAR (PRV)

Conclusions for skull-base case

Target under setup and range errors

- Significant changes in target coverage only under range errors
- Larger changes in target coverage for IMPT
- IMPT remains superior

OAR under setup and range errors

- Range errors are more critical than setup errors
- Dose more likely to exceed tolerances when using IMPT under range overshoots
- 3DCPT is sensitive to range errors too, but not for all organs (no general trend)
- Under setup errors IMPT remains superior (better spare of OAR)
- The benefits of IMPT in case of range overshoot is questionable

Solution

- Intelligent IMPT using robust optimization techniques against setup & range errors
- Add margin to OAR (PRV)

Overall Conclusion

If a clear a priori benefit of IMPT is observed in nominal plans, the use of IMPT remains attractive over 3DCPT even when taking into account the effects of setup errors and range uncertainties on the dose distribution. Nevertheless, refined range verification and further mitigation techniques need to be developed.