Image Fusion, Contouring, and Margins in SRS

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Overview

Review SRS uncertainties due to:

- image registration
- contouring accuracy
- contouring variability

Assess levels of uncertainty and greatest contributors to overall uncertainty

Discuss appropriate PTV margins to account for uncertainties in SRS

Registration Accuracy

Registration Accuracy

Accuracy depends on registration method:

- Local "box"-based rigid registrations can produce higher accuracy than global rigid registrations
- ROIs should be in close proximity target

Registration Accuracy

- Site-dependent:
  - Registration of spinal sites is less straightforward and has lower accuracy
  - Deformable image registration is tempting for spine registrations but the associated uncertainties are too high for use in SRS

Rigid vs. Deformable Registration

Accuracy depends on registration method:

- Rigid registration is more accurate than deformable registration

  rigid: ~1-2 mm uncertainty*

  deformable: ~5-7 mm uncertainty**

*Benchmark Test of Cranial CT/MR Registration • *IJROBP* • Kenneth *et al.* • 2010

**Need for application-based adaptation of DIR • *Med. Phys.* • Kirby *et al.* • 2013

**Performance of DIR in low contrast regions • *Med. Phys.* • Supple *et al.* • 2013

Registration Workflow Comparison

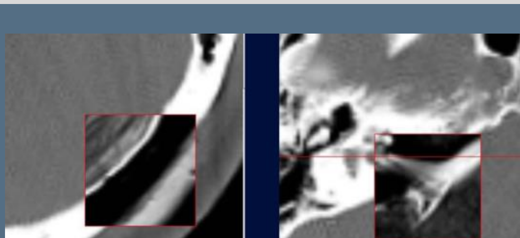
Simulation and planning images	Gamma Knife	Linac-based SRS
Planning	MRI*	CT
Contouring	MRI*	MRI or PET/CT
Fusion Type	single-modality rigid registration	multimodal rigid registration

* unless MRI is contraindicated

Modality

- Modality dependent:
  - Multi-modal registrations are typically less accurate than unimodal registrations, (especially for deformable registration)
  - Registering MRIs of differing sequences is not truly unimodal because of the difference in enhancement for certain regions
  - Different volumes may have different slice thicknesses

Co-Registration Accuracy



Visual evaluation of registration accuracy can be difficult.

Co-Registration Accuracy

7 patients, 5 observers

Registration accuracy, quantitative assessment: distance between correspondent markers

Patient number	ΔZ (mm) (mean±SD)	ΔP (mm) (mean±SD)	ΔS (mm) (mean±SD)	ΔS_{max} (mm)
1	0.37±0.78	1.17±0.89	1.54±1.05	2.50
2	0.11±0.33	0.88±0.52	0.96±0.58	1.41
3	0.64±1.27	1.15±1.15	1.92±1.13	3.62
6	0.36±0.41	1.70±0.86	1.89±0.75	2.72
7	0.39±1.15	0.81±0.79	1.54±1.26	3.48

Mean (over five anatomical landmarks) distance between correspondent markers: ΔZ, error along cranio-caudal direction (mm); ΔP, error in transaxial plane (mm); ΔS, error in 3D space (mm). Maximum discrepancy in 3D space: ΔS_{max}, maximum 3D error (mm).

max error:
3.7 mm

average error:
2.7 mm

Target delineation: Impact of registration • *Radio & Onc.* • Cattaneo *et al.* • 2005

Co-Registration Accuracy

45 institutions, 11 methods

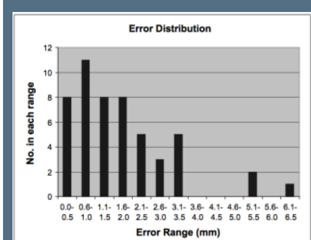


Fig. 5. Distribution of errors indicating the number of submissions falling within 5-mm error bins.

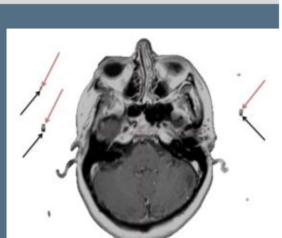
Registration accuracy:
1.8 mm +/- 2.2 mm

Manual registration better than automatic registration (p=0.02)

Benchmark Test of Cranial CT/MR Registration • *IJROBP* • Kenneth *et al.* • 2010

Frame-Based Registration

- When not using a single MR scan for GK contouring and planning, GammaPlan's auto registration can produce errors of up to 2 mm
  - Fiducial based registration compared to anatomical local box registration



MR to CT Registration Errors • *Med. Phys.* • Sudhyadhom *et al.* • 2014

Contouring Accuracy

Contouring Accuracy

Contouring accuracy is affected by:

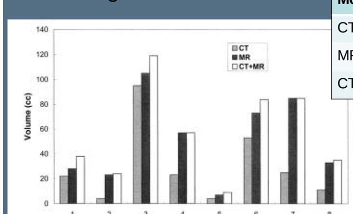
- Modality
- Spatial resolution
- Signal to noise ratio (SNR)
- MR field strength
- Planning image timing
- Contrast injection timing
- Additional factors: slice thickness, image artifacts, motion blur, spatial distortion

Modality

Modality affects GTV & CTV contouring:

- Tumor volumes across sites are typically larger on CT+MRI

Modality	Mean Volume
CT only	29.6 cm^3
MRI only	51.4 cm^3
CT+MRI	56.5 cm^3



MR GTVs were 74% larger than CT only

CT+MRI GTVs were 10% larger than MR only

Influence of MRI on GTV delineation • *IJROBP* • Emami *et al.* • 2003

Modality

Modality affects GTV & CTV contouring:
- Tumor volumes across sites are typically larger on CT+MRI

CT only

CT + MRI

A difference of 10 cm^3!

Modality	Mean Volume
CT only	59.5 cm^3
CT + MRI	69.6 cm^3

Interobserver variations GTV delineation • *Radio & Onc* • Weltens *et al.* • 2001

Spatial Resolution & SNR

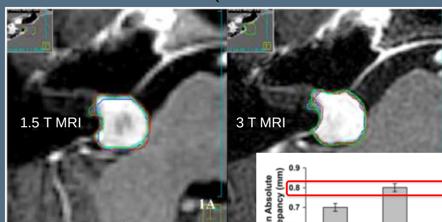
- Spatial resolution and SNR also affect imaging accuracy
  - Slice thickness contributes substantially to contouring and image fusion accuracy
  - SNR is greater concern for MRI
- In most cases, visual inspection is employed to determine appropriate resolution and SNR levels

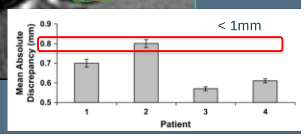
Slice Thickness

- Slice thickness affects image registration accuracy:
  - Thinner slices improve accuracy (improves interpolated image accuracy)
  - Typical planning CT and MRI slice thicknesses range from 1 mm to 3mm

MR Field Strength

MRI field strength effects spatial resolution and SNR, but 1.5 T is sufficient (small effects on contours)



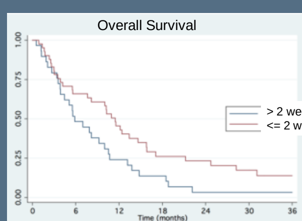


Evaluation of target localization using 3T MRI • *IJROBP* • MacFadden *et al.* • 2010

Planning Image Timing

73 patients, 123 lesions

Greater than 2 week wait times between MR acquisition and treatment significantly reduce survival



Overall survival (p = 0.039) for patients with MRI imaging to treatment period wait of > 2 weeks (blue) and ≤ 2 weeks (red).

Imaging to Treatment in RS: Too Long? • *IJROBP* • Seymour *et al.* • 2013

Timing of Contrast Injection

Contrast injection timing significantly impacts GTV.

Contrast injection delay (median of 65 minutes):
→ GTV increase in 82% of cases

Table 1. Observer measured tumour volumes for CT scans obtained immediately after administration of contrast medium and those obtained after a delay

Immediate scan			Delayed scan			
Lesion	Mean volume (SD) (mm^3)		Mean volume (SD) (mm^3)		% change in volume	3D shift in isocentre (mm)
A1	279	(79)	474	(59)	70	1.4
A2	not analysed					
B1	290	(87)	325	(63)	12	1.0
B2	879	(114)	1134	(103)	28	0.7
C	477	(15)	492	(21)	3	0.9
D1	1479	(32)	1798	(22)	21	1.3
D2	1780	(33)	1767	(35)	−1	0.4
E	1708	(33)	2093	(101)	22	0.6
F1	1807	(21)	2731	(39)	51	0.5
F2	2326	(23)	3179	(45)	36	1.5
G1	1961	(161)	2871	(559)	46	0.2
G2	3764	(234)	5952	(188)	58	1.4
H1	5333	(138)	6434	(166)	20	2.4
H2	not analysed					
I	11358	(344)	13047	(115)	14	4.6
J	19787	(894)	16688	(5009)	−16	not planned

Delineation brain mets on CT for RS: accuracy • *Br J Radiol* • Sidhu *et al.* • 2004

Additional Factors

- Slice thickness
- Image artifacts (e.g. metal artifacts)
- Motion blur
- Spatial distortion (especially MRI)

Contour Variation

Contour Variation

5 patients, 9 observers

Modality	Volume Ratio (largest: smallest)
CT only	(2.8, 1.8, 1.8, 1.9, 1.7)
CT + MRI	(2.4, 1.7, 1.9, 2.7, 1.5)

Volumes vary up to 30% of the mean volume

GTV range: as large as 174% and as small as 65.8% of mean volume

Interobserver variations GTV Delineation • *Radio & Onc.* • Weltens et al. • 2001

Contour Variation

7 patients, 5 observers

Modality	Concordance Index	Agreement Ratio (AR)
unregistered	14.1 +/- 12.7%	.24 +/- .18
registered	47.4 +/- 12.4%	.67+/- 15

CT+ registered MR reduces interobserver GTV variability

$$\text{Agreement ratio (AR)} = \frac{\text{common overlapping volume}}{\text{encompassing volume}}$$

Target delineation: interobserver variability • *Radio & Onc.* • Cattaneo *et al.* • 2005

Contour Variation

31 patients, 6 observers

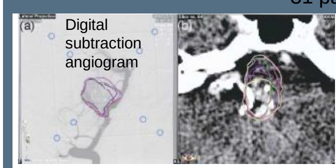


Fig. 1. Contouring variations in a patient with a brainstem arterio-venous malformation. (a) Target volume presented as different colors. All contours were automatically projected on computed tomography images used for further analysis (b).

Mean AR = 0.19 +/- 0.14

AR < 0.6 for all patients

$$\text{Agreement ratio (AR)} = \frac{\text{common overlapping volume}}{\text{encompassing volume}}$$

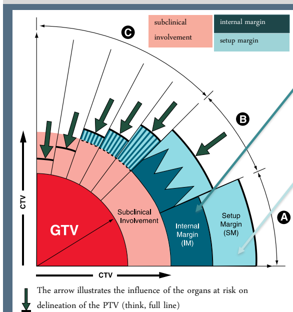
SRS for brain AVMs: Interobserver variability • IJROBP • Buis *et al.* • 2005

Margins

What margin for SRS?

- Margins should be sufficient to account for treatment uncertainties and guarantee target coverage
- They must be balanced to minimize potential negative side effects resulting from increased normal tissue dose (more important for SRS)
- Some clinics choose not to include margin expansions (CTV = PTV)

What is an appropriate margin?



- Internal margin (**IM**):
  - Residual motion, deformation
- Setup margin (**SM**):
  - Ensures adequate clinical coverage
  - Includes all uncertainties
  - Appropriate for hypofractionation

Journal of the ICRU: Volumes • Volume 4 Number 1 • 2004

Margins – not your simple PTV

Margin recipes based on standard fractionation (van Herk 1999) are not appropriate for few fractions:

$$M = 2.5\,\Sigma_{tot} + 0.7\sigma_{tot}$$

Several groups have adapted the van Herk recipe for hypofraction:

- Stroom and Heijmen (2003)
- Gordon and Siebers (2007)

ICRU Report 62 • van Herk *et al.* • 1999

Geometrical uncertainties, planning margins • *Rad & Onc* • Stroom *et al.* • 2002

PTV margins finite fractions & small systematic errors • *PMB* • Gordon *et al.* • 2007

Herschtal Margin for SBRT

- Adjusted van Herk formula as lower limit
- Developed method for estimating upper limit
- Model interpolates between limits
- Verified using MC simulation
- Specific to each clinic

Calculating margins for hypofractionated RT • *PMB* • Herschtal *et al.* • 2013

Summary

Summary

- Contours can vary substantially from physician to physician
  - Minimize by appropriate imaging choices (modality, MR field strength, etc.)
  - Generally not accounted for in PTV
- Contouring accuracy: small contribution to overall uncertainty (~1-2mm)
  - Minimized by imaging choices (slice thickness, reduction of image artifacts, etc.)
- Image registration: small contribution (~1-2mm)
  - Rigid registration, manual vs. automatic

Which of the following SRS workflow choices is likely to contribute MOST to overall uncertainty?

10%	1.	extend frame immobilization
19%	2.	CTV contouring variability
33%	3.	rigid image registration
24%	4.	3 mm MRI slice thickness
14%	5.	3 mm plan CT slice thickness

Which of the following SRS workflow choices is likely to contribute MOST to overall uncertainty?

1. Answer: CTV contouring variability

Refs: "Interobserver variations in gross tumor volume delineation of brain tumors on computed tomography and impact of magnetic resonance imaging", *Radiotherapy & Oncology* 60 (2001), p. 49-59.

"Target delineation in post-operative radiotherapy of brain gliomas: Interobserver variability and impact of image registration of MR (pre-op) images on treatment planning CTs", *Radiotherapy and Oncology* 75 (2005), p. 217-223.

Which of the following is currently LEAST appropriate for SRS?

11%	1.	mask immobilization
4%	2.	CBCT image guidance
18%	3.	contouring using PET-CT
21%	4.	deformable registration
14%	5.	planning on MRI

Which of the following is currently LEAST appropriate for SRS?

1. Answer: deformable registration.
2. Rigid registration is sufficient for the majority of SRS cases. Moreover, the uncertainty associated with deformable registration (as high as 7 mm) is too high to warrant use in SRS.

Refs: "The need for application-based adaptation of deformable image registration", *Medical Physics* 40 (2012), p. 1-9.

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