Evaluating patient specific pre-treatment quality assurance practices

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Gamma evaluation

- Gamma evaluation is a dose agreement metric that utilises a combined dose-spatial domain
- It's used by 100% of centres for IMRT PSQA in Australia recently surveyed, reported by Barber et al. 2017
- Publications have raised concerns regarding its application
  - Poor correlation with clinically significant dose errors, poor sensitivity and poor specificity
  - Lack of clinical intuitiveness
- There are alternatives

Divide & conquer gamma evaluation

- Stojadinovic et al. (2015) “Breaking bad IMRT QA practice”
- For errors in low dose regions, global gamma is insensitive and local gamma is overly sensitive
- Divide and conquer approach splits dose distribution into 4 regions: high dose (≥90%), high dose gradient (50%-90%), medium dose (20%-50%), low dose (<20%); and applies different criteria

Maximum allowed dose difference

- Jiang et al. (2006) “On dose distribution comparison”
- The MADD / normalised dose difference approach has spatial domain condensed to dose domain
  - the DTA criteria is converted to a dose difference (e.g. by multiplication against local dose gradient) and added to DD% for MADD
  - local dose difference is then evaluated against MADD; ratio is described as normalised dose difference
- Two variations: gamma and box, where box is simple multiplication and gamma is tighter

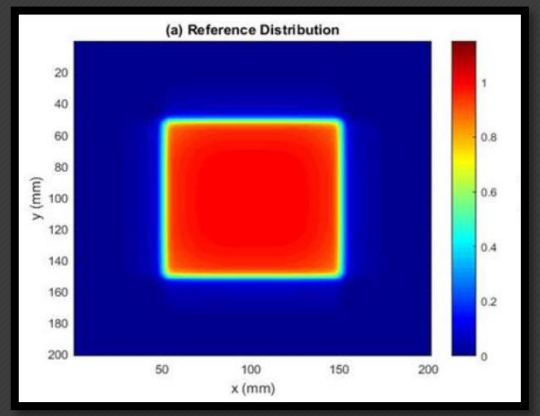
Objectives and methods

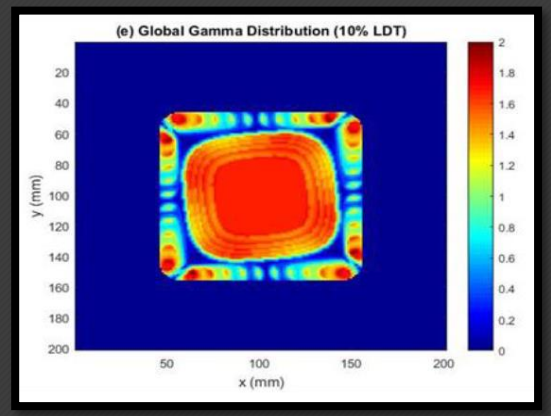
- MADD and D&C techniques were evaluated against local and global gamma analysis for 350 treatment plan PSQA datasets, obtained on an ArcCheck system (142 Tomo, 208 VMAT), for multiple DD% and DTA criteria

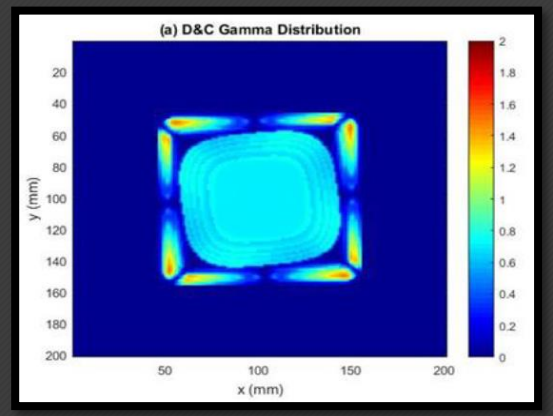
Modality	Accelerator	Results	MLC	TPS	Algorithm
Tomotherapy	Tomotherapy Unit Hi-Art II	142 plans	Binary MLC	Tomotherapy	CCC
VMAT	Varian 2liX	208 arcs	Millennium 120	ECLIPSE v13.5	AAA

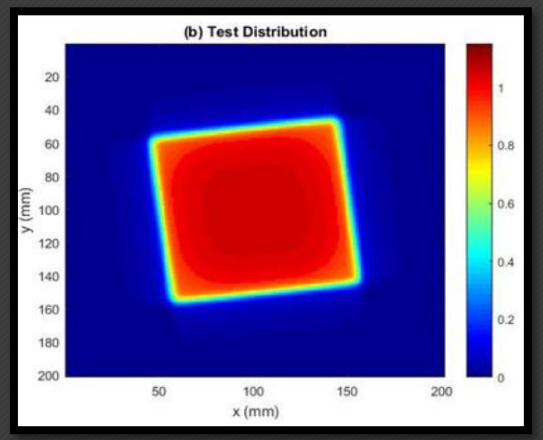
- Code developed in Matlab for this comparison

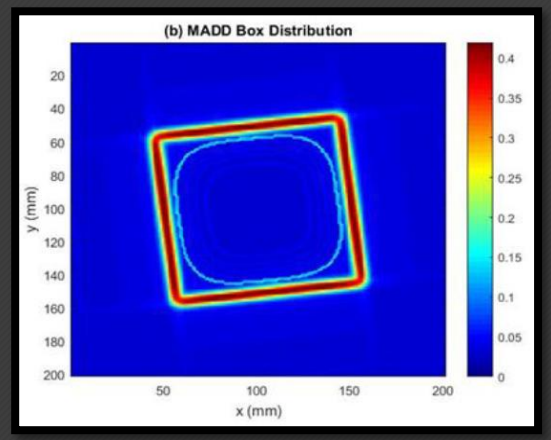
Aside: code validation

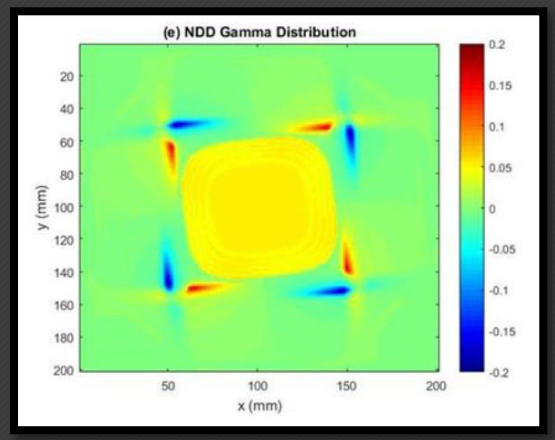












- Validated using Low & Dempsey (2003) data
- Approach followed by Jiang et al. (2006)
- Results were similar to SNC Patient

Objectives and methods

- Correlation between analysis results was assessed:
  - Pass rates for 5% LDT and 10% LDT
  - Pass rates for different criteria for any one technique
  - Pass rates for different techniques
- Correlation was determined to assess similarity of behaviour
  - i.e. do different techniques identify different PSQA results as having relatively high or low pass rates
- Coefficients of determination (R^2) - how much variation in independent variable can explain variable in dependent variable
- Statistical testing with Šidák correction to significance threshold, for multiple comparisons

Dose comparison results

Tomotherapy	1%/1 mm	2%/2 mm	2%/3 mm	3%/2 mm	3%/3 mm	5%/3 mm
G_{global} (5% LDT)	56.8±9.2	96.2±1.6	98.3±0.9	99.3±0.6	99.7±0.3	100±1
G_{global} (10% LDT)	56.4±9.1	95.8±1.8	98.2±0.9	99.2±0.7	99.7±0.3	100±1
G_{local} (5% LDT)	20.8±5.6	62.3±8.8	75.9±7.3	72.3±8.6	82.5±6.9	90.0±6.0
G_{local} (10% LDT)	22.6±5.6	66.9±8.5	80.5±6.9	77.5±7.9	87.2±6.1	94.4±3.9
$MADD_b$	83.0±6.0	99.4±0.5	99.7±0.3	99.9±0.1	100±1	100±1
$MADD_\gamma$	68.5±8.7	96.7±1.6	98.3±0.9	99.4±0.5	99.7±0.3	100±1
	[1%, 1.5%, 3%, 6%] / 1 mm	[2%, 3%, 5%, 8%] / 2 mm	[2%, 3%, 5%, 8%] / 3 mm	[3%, 4%, 8%, 10%] / 2 mm	[3%, 4%, 8%, 10%] / 3 mm	[5%, 7%, 10%, 15%] / 3 mm
D&C	62.5±7.7	94.1±3.8	97±3	98.2±1.9	99.3±1.1	100±1

Too high

Dose comparison results

Tomotherapy	1%/1 mm	2%/2 mm	2%/3 mm	3%/2 mm	3%/3 mm	5%/3 mm
G_{global} (5% LDT)	59.9±7.8	95.7±1.5	97.8±0.9	98.8±0.8	99.4±0.4	100±1
G_{global} (10% LDT)	55.1±7.7	94.6±1.9	97.3±1.1	98.4±1.1	99.3±0.6	100±1
G_{local} (5% LDT)	18.5±5.8	61.9±8.6	74.1±8.1	70.9±8.9	80.3±8.1	87.6±7.6
G_{local} (10% LDT)	21.7±5.6	71.1±5.5	82.9±3.5	80.8±5.1	88.9±3.2	95.4±2.3
$MADD_b$	86.1±7.5	99.5±0.4	99.8±0.2	99.9±0.1	100±1	100±1
$MADD_\gamma$	73.7±10.6	97.5±1.3	98.9±0.8	99.3±0.5	99.7±0.2	100±1
	[1%, 1.5%, 3%, 6%] / 1 mm	[2%, 3%, 5%, 8%] / 2 mm	[2%, 3%, 5%, 8%] / 3 mm	[3%, 4%, 8%, 10%] / 2 mm	[3%, 4%, 8%, 10%] / 3 mm	[5%, 7%, 10%, 15%] / 3 mm
D&C	62.3±10.5	94.3±5.5	97.1±3.3	98±3	98.8±2.3	99.9±0.6

Too high

Dose thresholding

- Results of gamma analysis results for 5% or 10% lower dose threshold were related for most cases ($R^2 \geq 0.64$)

Tomotherapy	1%/1 mm	2%/2 mm	2%/3 mm	3%/2 mm	3%/3 mm	5%/3 mm
G_{global}	0.952	0.973	0.982	0.984	0.991	0.981
G_{local}	0.959	0.849	0.747	0.805	0.694	0.569
VMAT						
G_{global}	0.576	0.845	0.883	0.948	0.961	0.986
G_{local}	0.83	0.352	0.173	0.273	0.125	0.038
SUMMARY OF P-VALUES Significance level $\alpha = 0.05$, $p \leq \alpha$ in all cases						

Comparison of criteria use

- Local gamma shows the least variation in behaviour with gamma criteria
- Generally greater R^2 between 2%/2mm, 2%/3mm, 3%/2mm, 3%/3mm results, agreeing with literature
- 5%/3mm results correlate least with other criteria (intuitive given pooling at 100% pass rate)

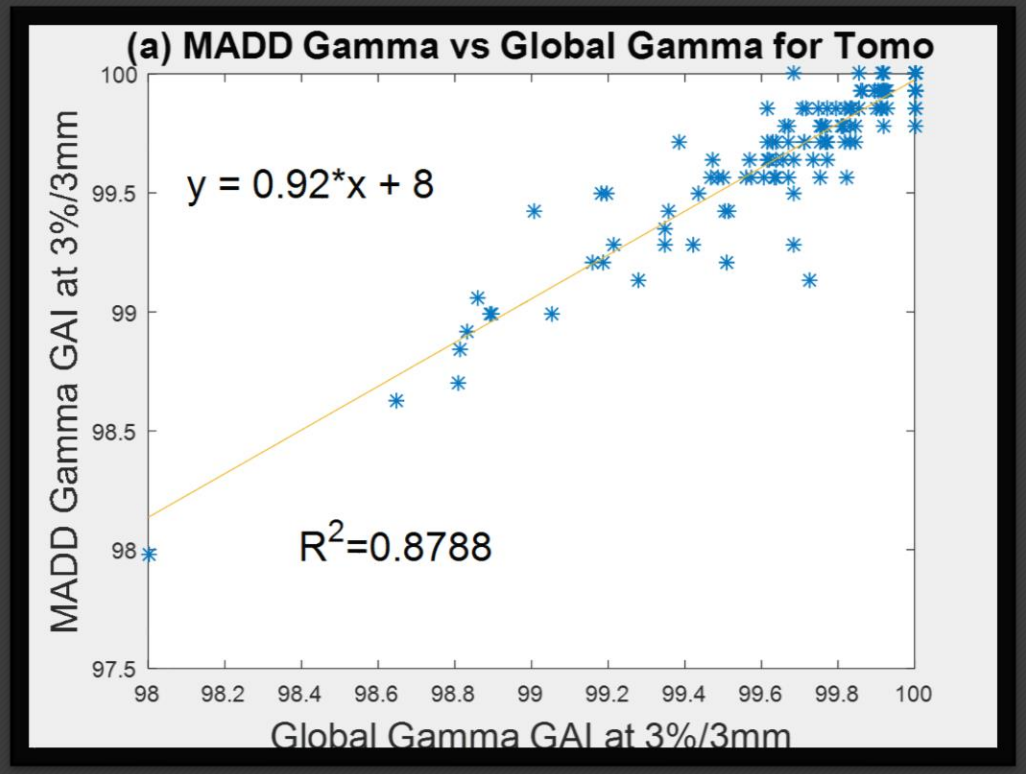
Colour Code	Tomotherapy	VMAT				
G_{global}	1%/1 mm	2%/2 mm	2%/3 mm	3%/2 mm	3%/3 mm	5%/3 mm
1%/1 mm		0.547	0.26	0.272	0.128	0.008
2%/2 mm	0.433		0.654	0.694	0.469	0.124
2%/3 mm	0.136	0.631		0.464	0.524	0.125
3%/2 mm	0.034	0.49	0.413		0.709	0.349
3%/3 mm	0.003	0.207	0.416	0.598		0.414
5%/3 mm	0.005	0.027	0.054	0.118	0.228	
G_{local}	1%/1 mm	2%/2 mm	2%/3 mm	3%/2 mm	3%/3 mm	5%/3 mm
1%/1 mm		0.75	0.462	0.736	0.514	0.508
2%/2 mm	0.752		0.777	0.941	0.768	0.613
2%/3 mm	0.525	0.886		0.757	0.891	0.606
3%/2 mm	0.689	0.949	0.855		0.82	0.718
3%/3 mm	0.489	0.837	0.94	0.891		0.796
5%/3 mm	0.296	0.566	0.646	0.646	0.814	
D&C	[1%HD …]/1 mm	[2%HD …]/2 mm	[2%HD …]/3 mm	[3%HD …]/2 mm	[3%HD …]/3 mm	[5%HD …]/3 mm
[1%HD …]/1 mm		0.401	0.251	0.253	0.174	0.04
[2%HD …]/2 mm	0.219		0.564	0.493	0.366	0.063
[2%HD …]/3 mm	0.075	0.638		0.702	0.591	0.139
[3%HD …]/2 mm	0.088	0.391	0.323		0.775	0.122
[3%HD …]/3 mm	0.073	0.22	0.388	0.509		0.162
[5%HD …]/3 mm	0.006	0.013	0.059	0.119	0.049	
$MADD_b$	1%/1 mm	2%/2 mm	2%/3 mm	3%/2 mm	3%/3 mm	5%/3 mm
1%/1 mm		0.033	0.018	0.006	0.003	0.001
2%/2 mm	0.056		0.641	0.324	0.244	0.086
2%/3 mm	0.021	0.822		0.378	0.377	0.015
3%/2 mm	0	0.471	0.603		0.566	0.131
3%/3 mm	0	0.375	0.507	0.694		0.099
5%/3 mm	0.03	0.01	0.015	0.02	0.043	
$MADD_\gamma$	1%/1 mm	2%/2 mm	2%/3 mm	3%/2 mm	3%/3 mm	5%/3 mm
1%/1 mm		0.135	0.092	0.059	0.023	0
2%/2 mm	0.424		0.872	0.5	0.401	0.037
2%/3 mm	0.215	0.8		0.38	0.428	0.034
3%/2 mm	0.028	0.466	0.504		0.688	0.245
3%/3 mm	0.003	0.289	0.482	0.75		0.304
5%/3 mm	0.006	0.051	0.064	0.169	0.26	
SUMMARY OF P-VALUES						
Sidak corrected significance level $\alpha_{sid} = 0.003$, $p_{sid} \leq \alpha_{sid}$ in all cases						

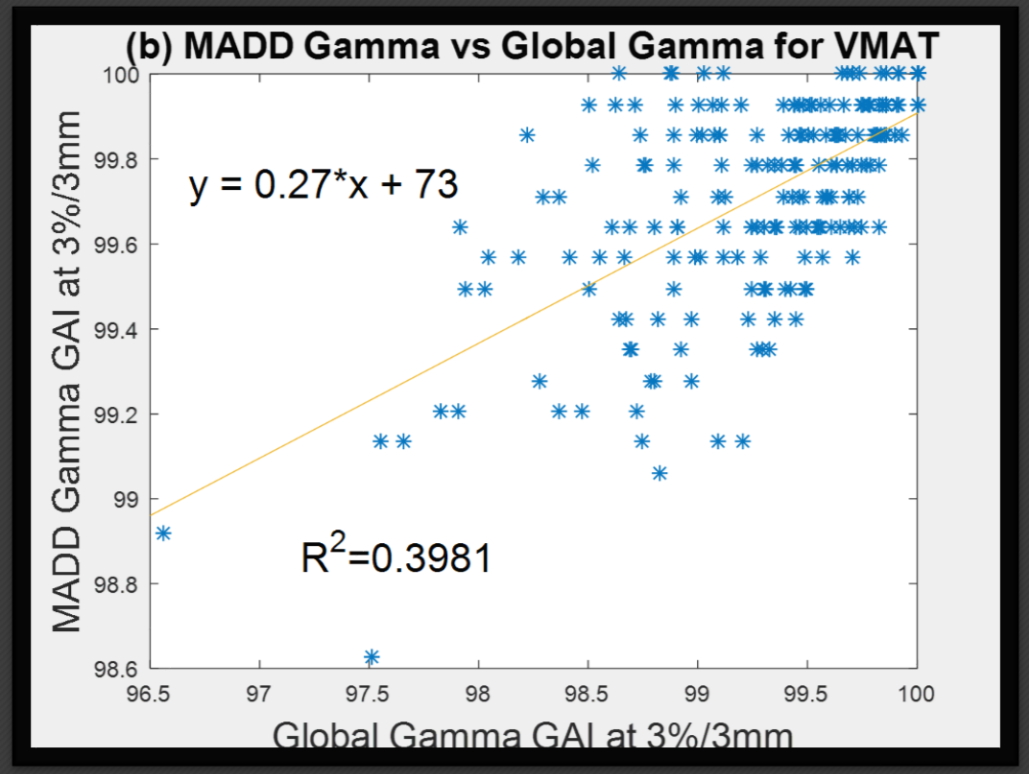
Comparison of techniques

- Behaviour of MADD similar to global gamma (in terms of plans receiver high or low pass rates)
- Correlations stronger for Tomo, potentially related to treatment dose gradients

Colour Code	Tomotherapy	VMAT			
1%/1 mm	G_{global}	G_{local}	D&C[1%HD …]/1 mm	$MADD_b$	$MADD_\gamma$
G_{global}		0.325	0.432	0.222	0.197
G_{local}	0.391		0.5	0	0.006
D&C[1%HD …]/1 mm	0.498	0.355		0.041	0.014
$MADD_b$	0.452	0.173	0.222		0.936
$MADD_\gamma$	0.514	0.189	0.236	0.909	
2%/2 mm	G_{global}	G_{local}	D&C[2%HD …]/2 mm	$MADD_b$	$MADD_\gamma$
G_{global}		0.531	0.237	0.197	0.151
G_{local}	0.118		0.195	0.067	0.039
D&C[2%HD …]/2 mm	0.1	0.13		0.033	0.005
$MADD_b$	0.297	0	0.039		0.612
$MADD_\gamma$	0.722	0.111	0.064	0.405	
2%/3 mm	G_{global}	G_{local}	D&C[2%HD …]/3 mm	$MADD_b$	$MADD_\gamma$
G_{global}		0.367	0.164	0.28	0.297
G_{local}	0.062		0.049	0.03	0.031
D&C[2%HD …]/3 mm	0.098	0.053		0.052	0.021
$MADD_b$	0.441	0	0.034		0.453
$MADD_\gamma$	0.841	0.081	0.087	0.444	
3%/2 mm	G_{global}	G_{local}	D&C[3%HD …]/2 mm	$MADD_b$	$MADD_\gamma$
G_{global}		0.4	0.312	0.292	0.441
G_{local}	0.006		0.151	0.068	0.124
D&C[3%HD …]/2 mm	0.105	0.019		0.142	0.142
$MADD_b$	0.254	0.011	0.031		0.348
$MADD_\gamma$	0.804	0.002	0.079	0.359	
3%/3 mm	G_{global}	G_{local}	D&C[3%HD …]/3 mm	$MADD_b$	$MADD_\gamma$
G_{global}		0.244	0.31	0.23	0.398
G_{local}	0		0.059	0.018	0.082
D&C[3%HD …]/3 mm	0.126	0		0.058	0.097
$MADD_b$	0.457	0.008	0.041		0.343
$MADD_\gamma$	0.879	0	0.086	0.451	
5%/3 mm	G_{global}	G_{local}	D&C[5%HD …]/3 mm	$MADD_b$	$MADD_\gamma$
G_{global}		0.095	0.173	0.201	0.573
G_{local}	0.004		0.015	0.028	0.036
D&C[5%HD …]/3 mm	0.078	0.003		0.081	0.114
$MADD_b$	0.078	0.003	0		0.209
$MADD_\gamma$	0.757	0.001	0.059	0.225	
SUMMARY OF P-VALUES					
Sidak corrected significance level $\alpha_{sid} = 0.005$, $p_{sid} \leq \alpha_{sid}$ in most cases except					
5%/3 mm: p_{sid} (D&C vs G) = 0.988, p_{sid} (MADDB vs G) = 0.007, p_{sid} (MADDG vs G) = 0.999, p_{sid} (D&C vs MADDB) = 0.793, p_{sid} (D&C vs MADDG) = 0.983					
3%/2 mm: p_{sid} (D&C vs G) = 0.183; 3%/3 mm: psid (D&C vs G) = 0.023; 5%/3 mm: psid (D&C vs G) = 0.560, p_{sid} (D&C vs MADDB) = 0.015, p_{sid} (D&C vs MADDG) = 0.081					

Examples of large and small R^2





Conclusions

- 5% vs. 10% LDT doesn't change behaviour too much – you'd have similar results with both, assuming adjusted action level
- MADD box method provides high pass rates (arguably too high)
- D&C behaves differently to gamma evaluation – so if you use it, you can't expect similar sensitivity / specificity
- MADD gamma method behaves similarly to popular gamma method, is easy to implement, and provides clinically intuitive results (you get a pass rate, but also a DD%)