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SSIM Index for the Quantitative Evaluation of Radiotherapy Dose Distribution

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PURPOSE

Gamma Index (γ) has been used for more than 10 years in clinic for IMRT/VMAT QA evaluation, many researchers have found γ has limitations and explored different, more sensitive methods and metrics that could be used more effectively for evaluating the accuracy of dose algorithms, delivery systems, and QA devices. Those reports suggested the retirement of the conventional QA metrics for IMRT/VMAT dose verification [1-5]. We have explored a new dose QA metric, the structure similarity (SSIM) index [6] that compares local patterns of pixel intensities of images.

METHODS and MATERIALS

SSIM index in the reference [6] is defined as a function of luminance (*l*), contrast (*c*), and structure (*s*):

$$S(x,y) = f\,(l(x,y),\ c(x,y),\ s(x,y)) \qquad (1)$$

where *l*, *c*, *s* in the above equation we redefine as dose value, dose to background noise, and the shape of dose map, respectively. The underlying principle of the error-sensitivity approach is that perceptual quality is best estimated by quantifying the visibility of errors [6]. A set of error-induced test patterns and IMRT fields have been evaluated using both SSIM index and gamma index with the use of three different QA detectors: portal dosimetry, diode-array detector, and transmission detector. Matlab programs were written to read each detector's signal data and convert them to dose. Gamma index and SSIM index programs were used to calculate the Gamma index and SSIM index values and maps.

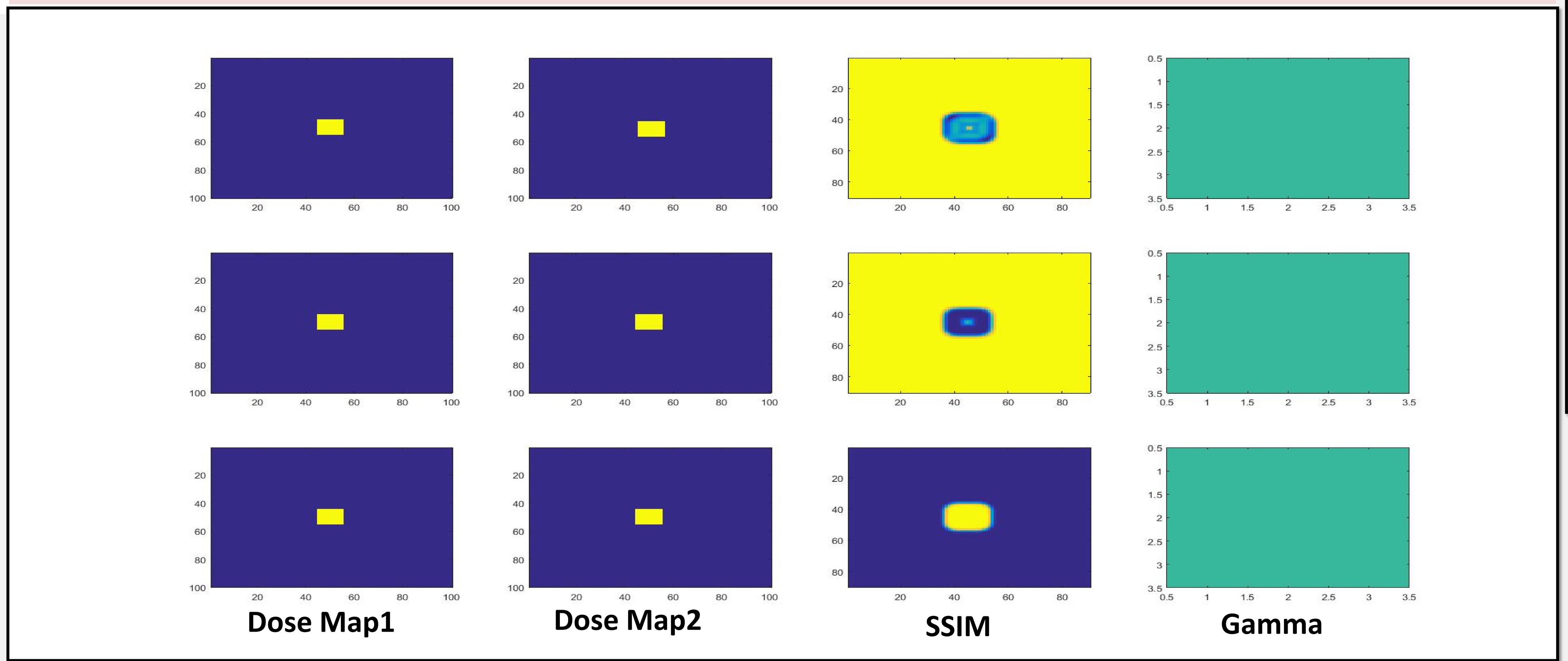

FIGURE 1: Top row from left to right: a 100x100 image with 1 mm resolution and 100 cGy dose box in the center; a 1 mm shift for the dose box; SSIM index map, gamma index map. Middle row from left to right: same image as the top row; dose increase to 102 cGy without a shift; SSIM index map, gamma index map. Bottom row from left to right: same image as top row, same image but with 2 cGy background, SSIM index map, gamma index map. Gamma index failed to detect the dose and distance differences but SSIM detected.

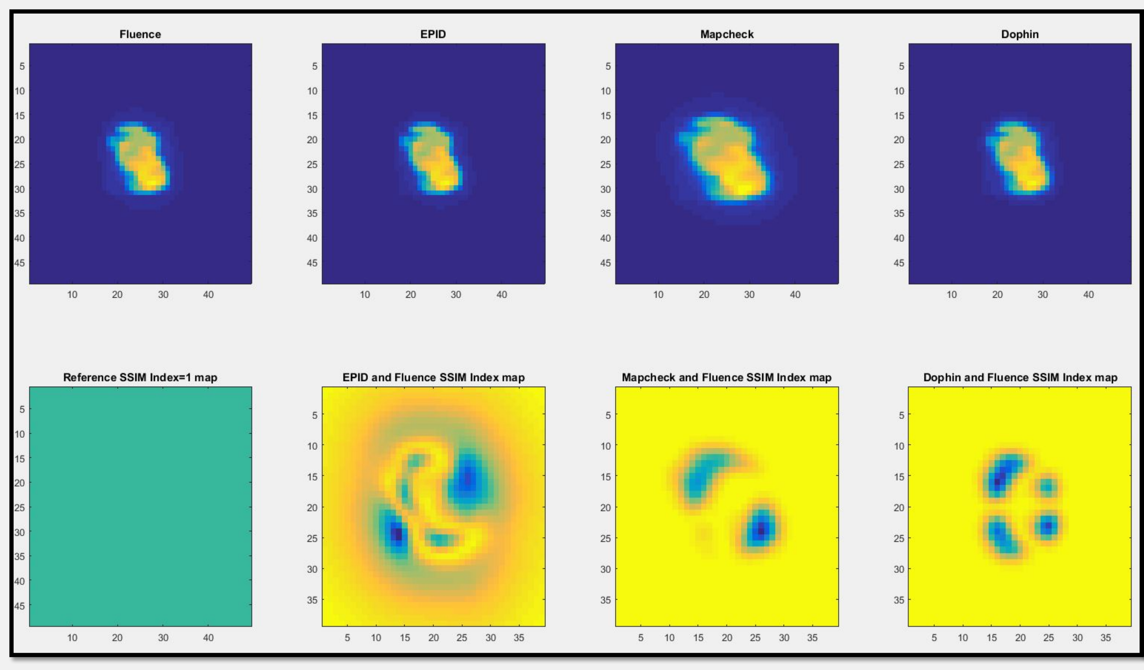

FIGURE 2. Brain Case 1. Top row from left to right: fluence map from plan, EPID, MapCHECK, and Dolphin; bottom row from left to right: SSIM map for ideal scenario, EPID, MapCHECK, and Dolphin.

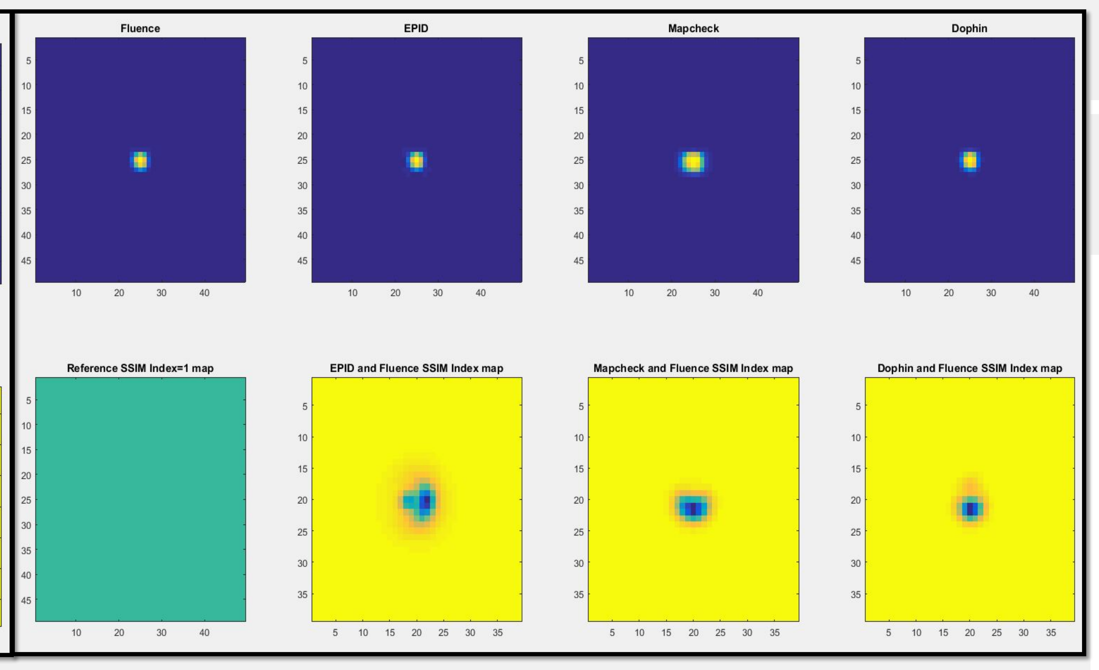

FIGURE 3. Brain Case 2. Top row from left: fluence map from plan, EPID, MapCHECK, and Dolphin; bottom row from left: SSIM map for ideal scenario, EPID, MapCHECK, and Dolphin.

RESULTS and DISCUSSIONS

Figure 1 demonstrate the higher sensitivity of SSIM index over gamma index in detecting systematic errors in radiotherapy delivery through three sets of images. Figures 2-7 illustrate different SSIM index maps using three commonly used QA devices (portal dosimetry, diode-array detector, transmission detector). Figures 2-6 demonstrate the comparisons of original fluences and measured 2D fluences by EPID, MapCHECK, Dolphin for brain, GI, and Lung cases. SSIM maps show the ability to detect effects due to devices differences and local dosimetry failure. Figure 7 summarizes the SSIM index comparisons for Dolphin, MapCHECK, and EPID, respectively.

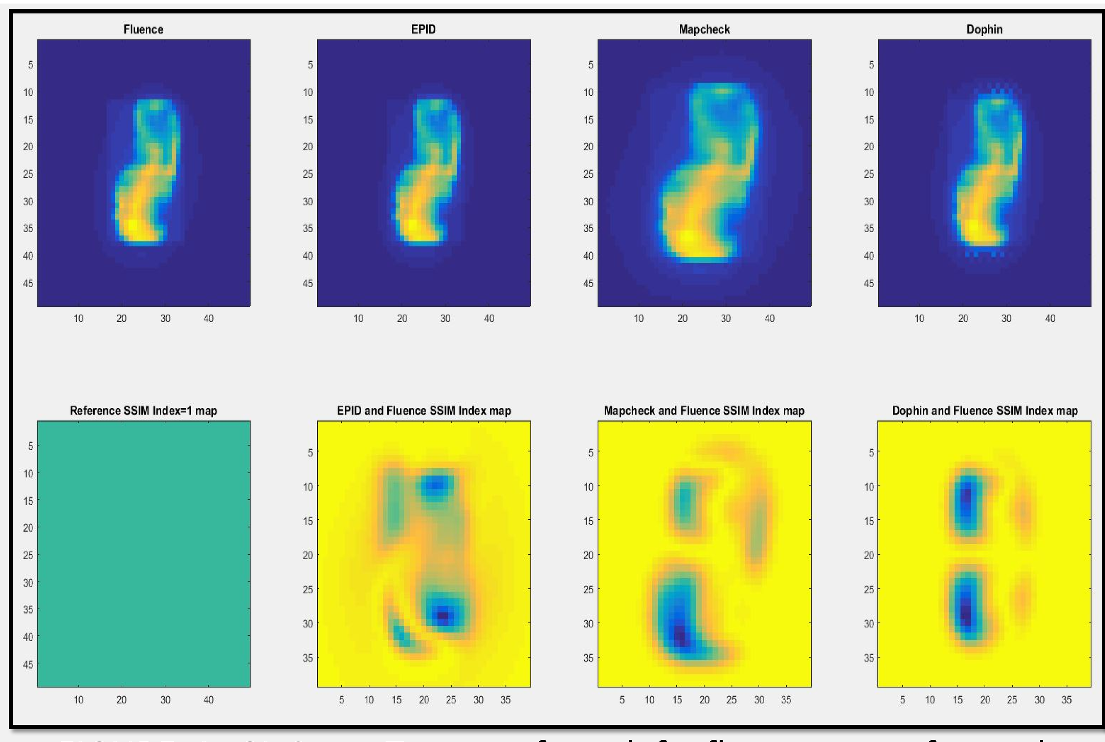

FIGURE 4. GI Case. Top row from left: fluence map from plan, EPID, MapCHECK, and Dolphin; bottom row from left: SSIM map for ideal scenario, EPID, MapCHECK, and Dolphin.

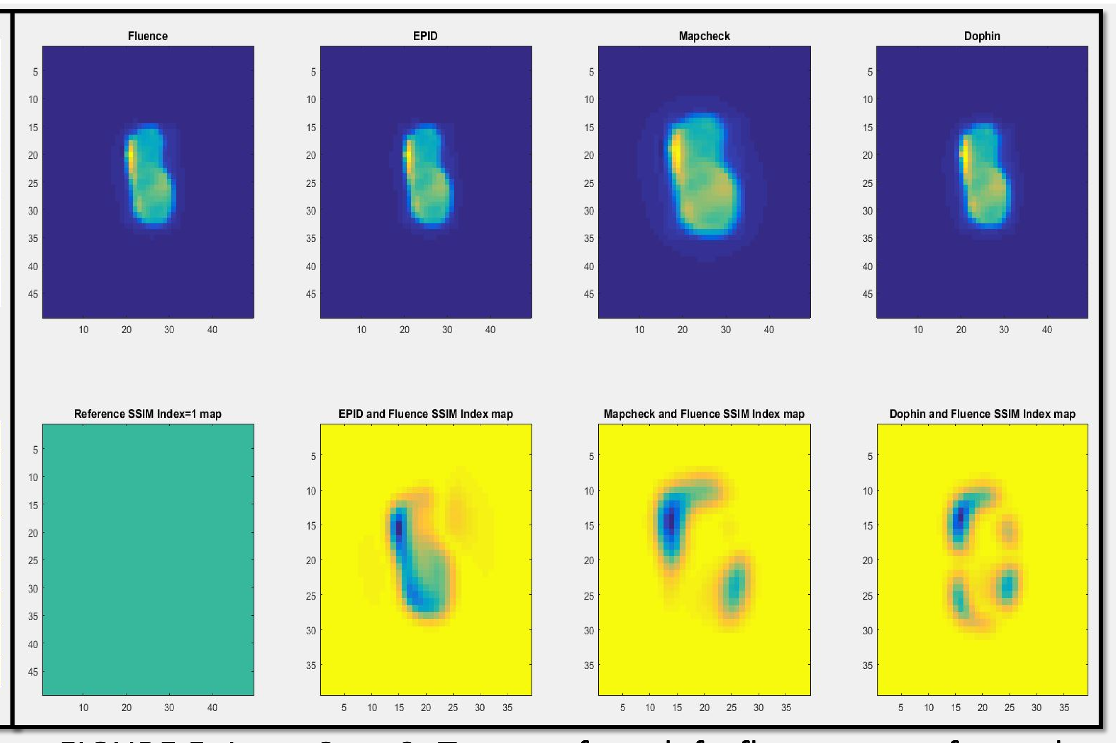

FIGURE 5. Lung Case 2: Top row from left: fluence map from plan, EPID, MapCHECK, and Dolphin; bottom row from left: SSIM map for ideal scenario, EPID, MapCHECK, and Dolphin.

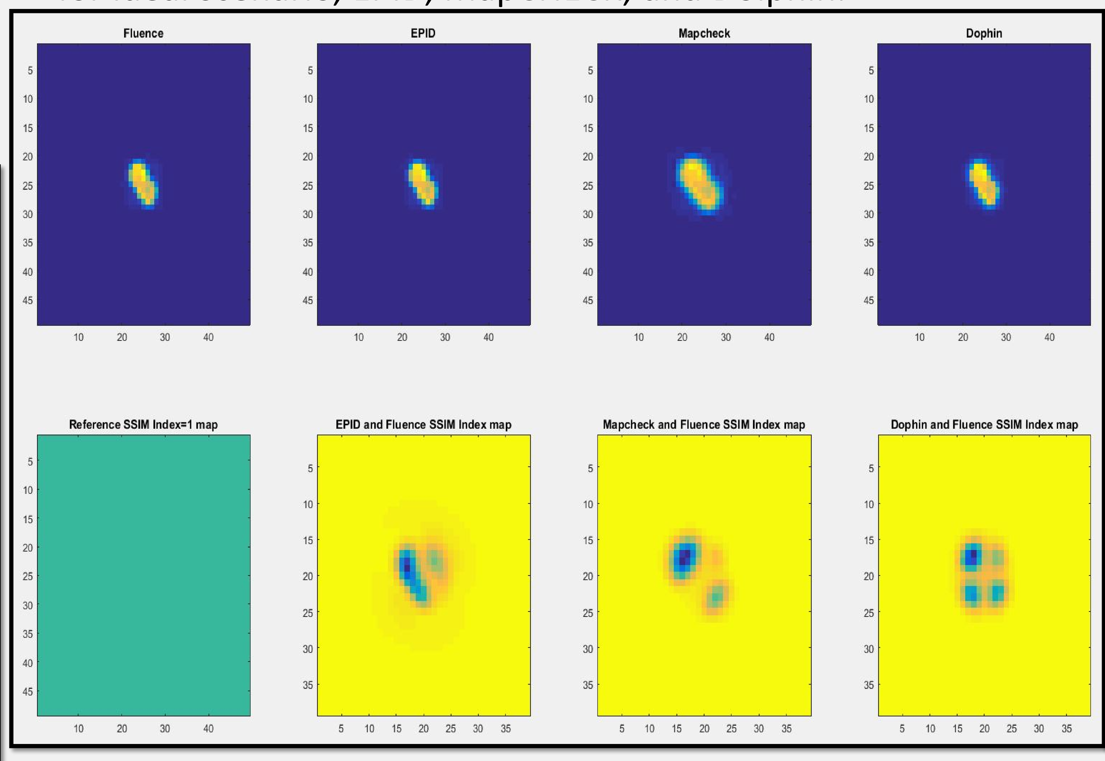

FIGURE 6. Lung Case 2. Top row from left to right: fluence map from plan, EPID, MapCHECK, and Dolphin; bottom row from left to right: SSIM map for ideal scenario, EPID, MapCHECK, and Dolphin.

Plan	Field 01	Field 02	Field 03	Field 04	Field 05	Field 06	Field 07
Lung1	0.9976	0.9947	0.9938	0.9926	0.9922		
Lung2	0.9997	0.9999	0.9984	0.997	0.9978	0.9999	0.997
Brain1	0.9999	0.9998	0.9999	0.9994	0.9995	0.9991	
Brain2	1.0000	0.9999	1.0000	1.0000	1.0000	1.0000	
GI	0.9973	0.9997	0.9985	0.9988	0.9997	0.9991	0.998

Plan	Field 01	Field 02	Field 03	Field 04	Field 05	Field 06	Field 07
Lung1	0.9884	0.9854	0.9859	0.9831	0.9787		
Lung2	0.9983	0.9984	0.9951	0.9942	0.996	0.999	0.993
Brain1	0.9995	0.9993	0.9995	0.9987	0.9988	0.9976	
Brain2	0.9999	0.9995	0.9998	0.9998	0.9998	0.9998	
GI	0.9909	0.9978	0.9969	0.9979	0.9987	0.9979	0.997

Plan	Field 01	Field 02	Field 03	Field 04	Field 05	Field 06	Field 07
Lung1	1.000	1.000	1.000	1.000	1.000		
Lung2	1.000	1.000	1.000	1.000	1.000	1.000	1.00
Brain1	1.000	1.000	1.000	1.000	1.000	1.000	
Brain2	1.000	1.000	1.000	1.000	1.000	1.000	
GI	1.000	1.000	1.000	1.000	1.000	1.000	1.00

FIGURE 7. SSIM index comparison for Dolphin (top), MapCHECK (middle), EPID (bottom).

CONCLUSIONS

We have introduced a new evaluation metric (SSIM index) for dose distribution and device comparison. Our results show that SSIM index is more sensitive than gamma index for changes of distance, intensity, contrast, and modality. From the comparison study, portal dosimetry is the most similar to the planning fluence map based on SSIM index, followed by transmission detector and diode-array detector maps.

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