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Quantitative thermal imaging biomarkers to detect acute skin toxicity from breast radiation therapy using supervised machine learning

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Citation:

Table 1
Demographic and clinical information of the patients (n=90) involved in the study.

Demographic and Clinical Characteristics	CTCAE ≥2 (n= 37)		CTCAE ≤1 (n= 53)		p-values
	(n)	%	(n)	%	
Age (Years)					0.87
Mean Age (±SD)	59 (±12)		59 (±12)		
Maximum Age	85	---	88	---	
Minimum Age	32	---	28	---	
Race					0.84
Asian	5	13.5%	14	26.4%	
Black	2	5.4%	0	0%	
Caucasian	26	70.3%	33	62.3%	
Hispanic	1	2.7%	5	9.4%	
Other	3	8.1%	1	1.9%	
Cup Size[a]					0.22
A	5	13.5%	11	20.8%	
B	10	27%	6	11.3%	
C	6	16.2%	9	17%	
D	8	21.6%	11	20.8%	
E	2	5.4%	10	18.9%	
Not Applicable	6	16.2%	6	11.3%	
Histological Type					0.20
IDC	22	59.5%	34	64.2%	
DCIS	12	32.4%	10	18.9%	
ILC	2	5.4%	7	13.2%	
IMC	1	2.7%	0	0%	
Not Evaluated	0	0%	2	3.8%	

Demographic and Clinical Characteristics	CTCAE ≥2 (n= 37)		CTCAE ≤1 (n= 53)		
	(n)	%	(n)	%	p-values
Tumor Grade					0.30
Low	4	10.8%	11	20.8%	
Intermediate	22	59.5%	23	43.4%	
High	11	29.7%	19	35.8%	
Molecular Subtype					
ER Status:					0.46
Positive	29	78.4%	40	75.5%	
Negative	6	16.2%	6	11.3%	
Undefined	2	5.4%	7	13.2%	
PR Status:					0.46
Positive	24	64.9%	33	62.3%	
Negative	11	29.7%	13	24.5%	
Undefined	2	5.3%	7	13.2%	
HER2 Status:					0.41
Positive	2	5.4%	6	11.3%	
Negative	33	89.2%	41	77.4%	
Undefined	2	5.4%	6	11.3%	
Tumor Size (cm)[c]					0.83
Average Size (±SD)	2.2 (±2.2)	---	2.2 (±1.3)	---	
Maximum Size	12.7	---	6.5	---	
Minimum Size	0.2	---	0.1	---	
Tumor Laterality					1.00
Left	18	48.6%	26	49.1%	
Right	19	51.4%	27	50.9%	
Surgical Procedure					0.76
Mastectomy	6	16.2%	7	13.2%	
Lumpectomy	31	83.8%	46	86.8%	

Characteristics	(n)	%	(n)	%	p-values
Menopausal Status					0.26
Pre/Peri-Menopausal	9	24.3%	8	15.1%	
Post-Menopausal	22	59.5%	41	77.4%	
Unknown	6	16.2%	4	7.5%	
Adjuvant Chemotherapy					0.65
Yes	14	37.8%	17	32.1%	
No	22	59.5%	36	67.9%	
Unknown	1	2.7%	0	0%	
Adjuvant Chemotherapy Type					0.87
AC-T	6	42.9%	6	35.3%	
FEC-D	3	21.4%	2	11.8%	
TC	2	14.3%	4	23.5%	
PACL	1	7.1%	1	5.9%	
Unknown	2	14.3%	4	23.5%	
Local vs Locoregional Irradiation					0.50
Locoregional (4-Field)	14	37.8%	16	30.2%	
Local (Whole breast only)	23	62.2%	37	69.8%	
Radiation Dose to Skin Volume (cGy)					0.17
Average dose (±SD)	2313 (±591)	---	2182 (±253)	---	
Maximum dose	4500	---	3405	---	
Minimum dose	2128	---	2000	---	
Tumor Laterality					1.00
Left	18	48.6%	26	49.1%	
Right	19	51.4%	27	50.9%	

[a] Cup sizes follow the North American standard. [b] Grading was performed through the Nottingham score. [c] Tumor sizes were obtained through pathology reports.

Abbreviations: CTCAE= Common Terminology Criteria for Adverse Events; IDC= Invasive Ductal Carcinoma; DCIS= Ductal Carcinoma in Situ; ILC= Invasive Lobular Carcinoma; IMC= Invasive Mammary Carcinoma; ER= Estrogen Receptor; PR= Progesterone Receptor; HER2= Human Epidermal Growth Factor Receptor 2; SD: Standard deviation. P values were calculated using Fisher's exact test, Mann-Whitney U test and T-Test as appropriate.

Table 2

Prediction of the skin toxicity using the optimal feature sets (relative change from the baseline at $f_x = 5$)

Experiment	Optimal Feature Set	Tr Acc	Te Acc	Te AUC	Te Sen	Te Spec
One	Max. Temp (°C), Median Temp (°C), Mean Temp (°C), Skewness, Kurtosis	0.79	0.73	0.90	0.86	0.63
Two	Median Temp (°C), Mean Temp (°C), Skewness, Kurtosis	0.76	0.73	0.84	0.71	0.75
Three	Mean Temp (°C), GLCM-COR, GLCM-ENE, GLCM-HOM, GLRLM-GLN	**0.91**	**0.87**	**0.98**	0.86	**0.88**
Four	Mean Temp (°C), GLCM-COR, GLCM-ENE, GLRLM-LRLGLE	0.86	0.80	0.93	**1.0**	0.63

Bolded values denote the highest value amongst the feature set for predictive accuracy and AUC values.

Abbreviations: Tr = Train; Te = Test; Sen = Sensitivity; Spec = Specificity; Acc = Accuracy; AUC = Area Under the Curve; GLCM= Grey Level Co-Occurrence Matrix; GLRLM= Grey level Run Length Matrix; COR= Correlation; ENE= Energy; HOM= Homogeneity; GLN= Gray Level Non-Uniformity; LRLGLE= Long Run Low Grey Level Emphasis.