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

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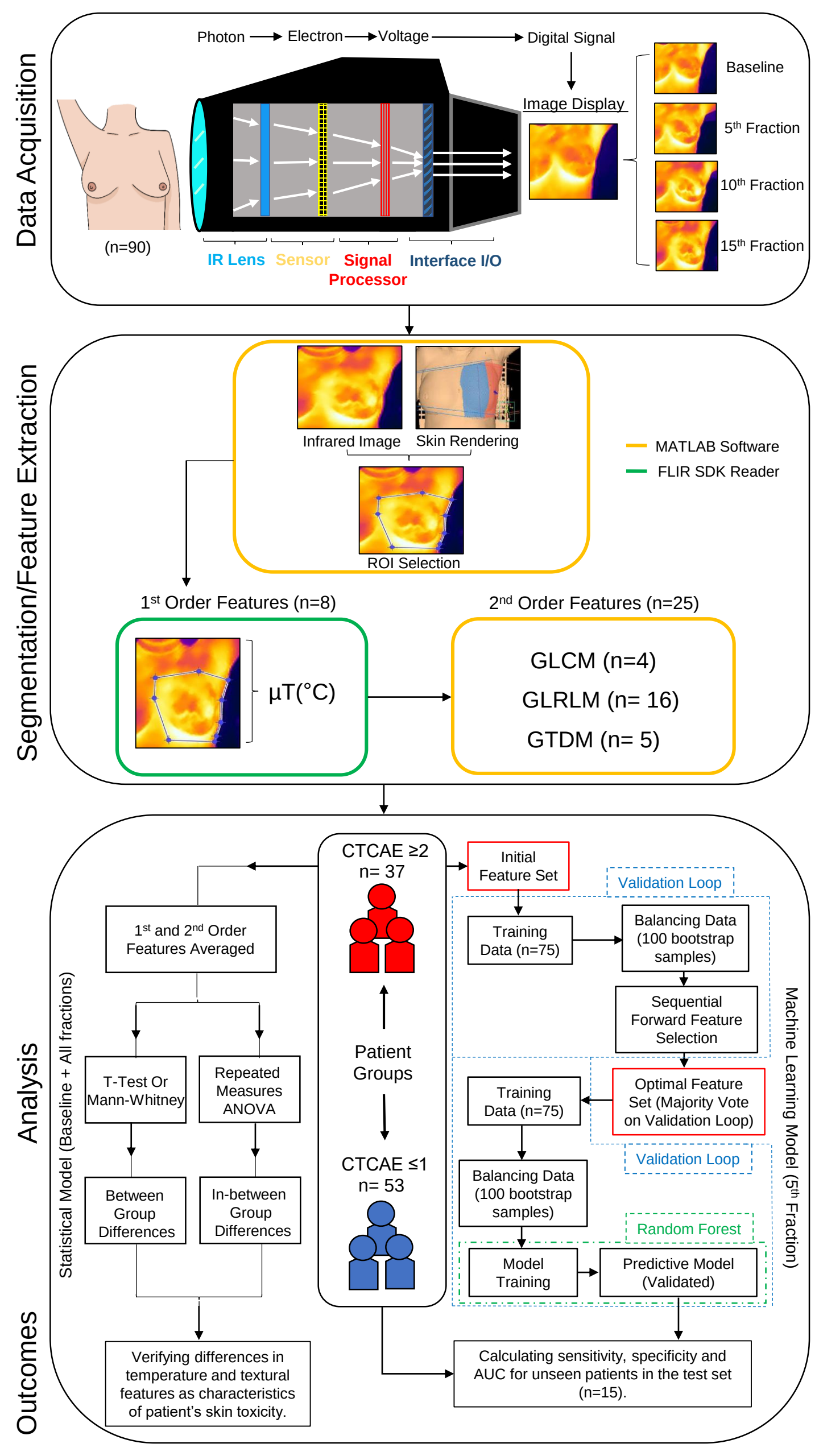
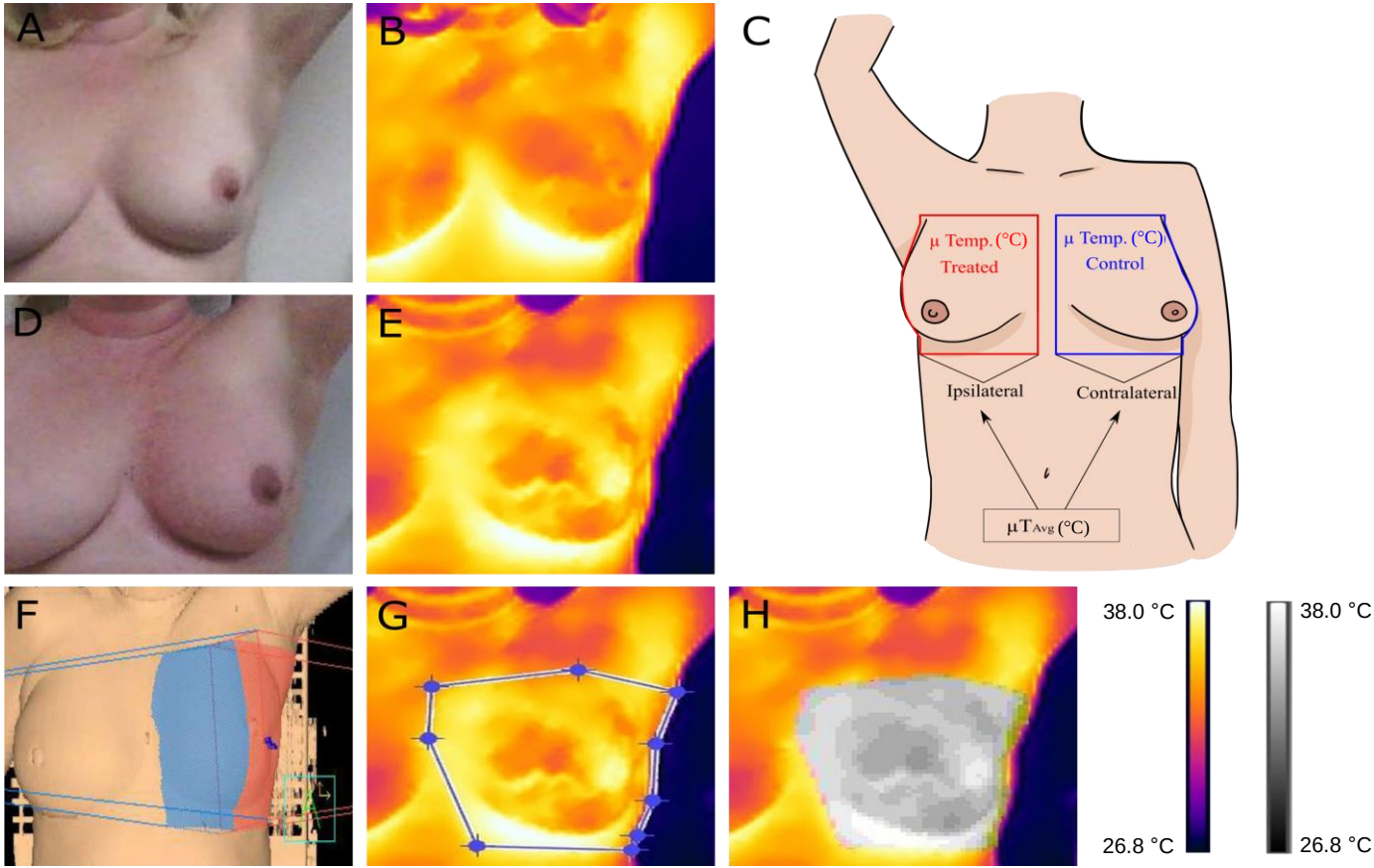
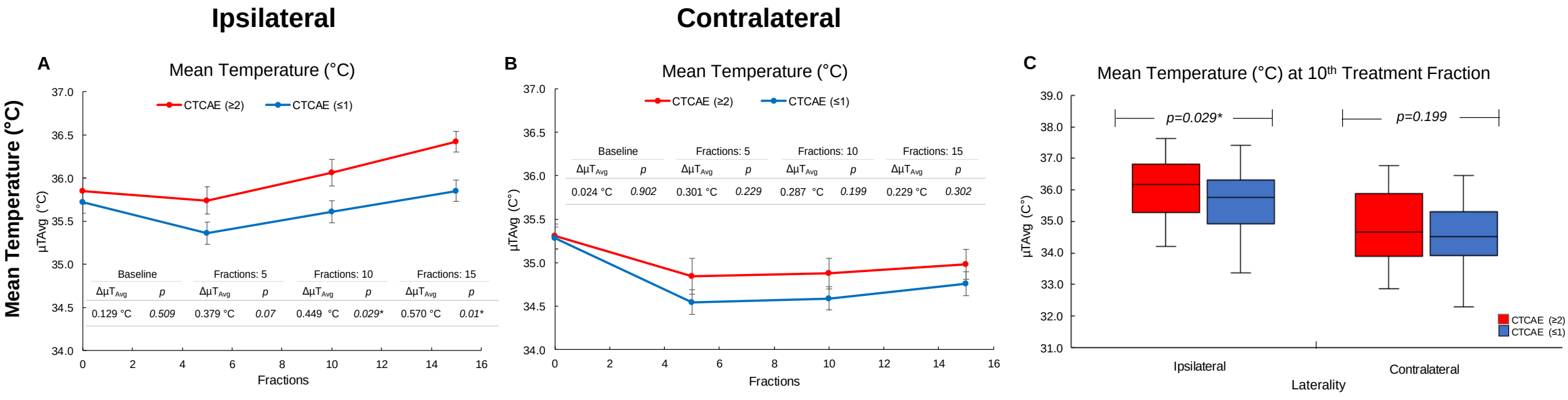

Data Acquisition
Photon
Electron
Voltage
Digital Signal
Image Display
Baseline
5th Fraction
10th Fraction
15th Fraction
(n=90)
IR Lens
Sensor
Signal Processor
Interface I/O
Segmentation/Feature Extraction
Infrared Image
Skin Rendering
ROI Selection
MATLAB Software
FLIR SDK Reader
1st Order Features (n=8)
μT(°C)
2nd Order Features (n=25)
GLCM (n=4)
GLRLM (n= 16)
GTDM (n= 5)
Analysis
Statistical Model (Baseline + All fractions)
1st and 2nd Order Features Averaged
T-Test Or Mann-Whitney
Repeated Measures ANOVA
Between Group Differences
In-between Group Differences
CTCAE ≥2
n= 37
Patient Groups
CTCAE ≤1
n= 53
Initial Feature Set
Validation Loop
Training Data (n=75)
Balancing Data (100 bootstrap samples)
Sequential Forward Feature Selection
Optimal Feature Set (Majority Vote on Validation Loop)
Validation Loop
Random Forest
Model Training
Predictive Model (Validated)
Machine Learning Model (5th Fraction)
Outcomes
Verifying differences in temperature and textural features as characteristics of patient's skin toxicity.
Calculating sensitivity, specificity and AUC for unseen patients in the test set (n=15).

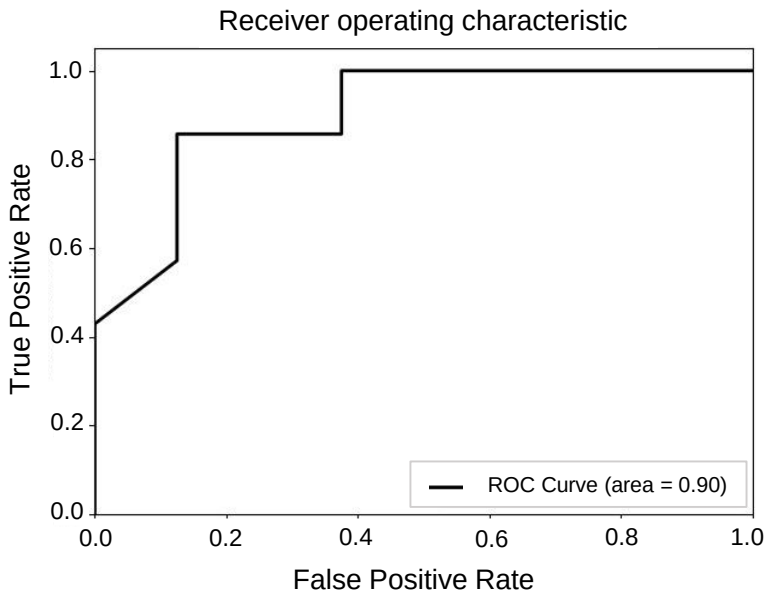

A
B
C
D
E
F
G
H
μ Temp. (°C)
Treated
μ Temp. (°C)
Control
Ipsilateral
Contralateral
μTAvg (°C)
38.0 °C
26.8 °C
38.0 °C
26.8 °C


Ipsilateral
Contralateral
Mean Temperature (°C)
A
Mean Temperature (°C)
CTCAE (≥2)
CTCAE (≤1)
μTAvg (°C)
Fractions
Baseline
Fractions: 5
Fractions: 10
Fractions: 15
ΔμT Avg
p
0.129 °C
0.509
0.379 °C
0.07
0.449 °C
0.029*
0.570 °C
0.01*
B
Mean Temperature (°C)
CTCAE (≥2)
CTCAE (≤1)
μTAvg (C°)
Fractions
Baseline
Fractions: 5
Fractions: 10
Fractions: 15
ΔμT Avg
p
0.024 °C
0.902
0.301 °C
0.229
0.287 °C
0.199
0.229 °C
0.302
C
Mean Temperature (°C) at 10th Treatment Fraction
p=0.029*
p=0.199
μTAvg (C°)
CTCAE (≥2)
CTCAE (≤1)
Ipsilateral
Contralateral
Laterality

Experiment One

Optimal Feature Set:

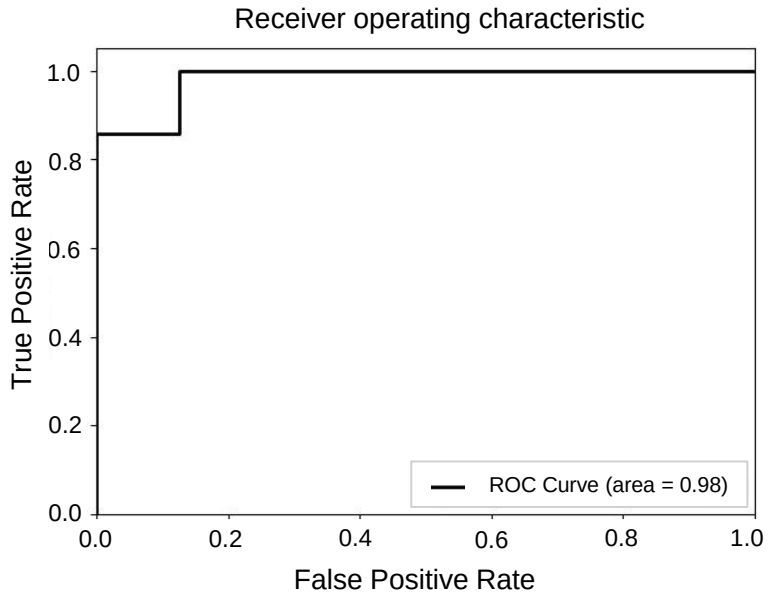
Max. Temp(°C), Median Temp(°C),
Mean Temp(°C) Skewness, Kurtosis

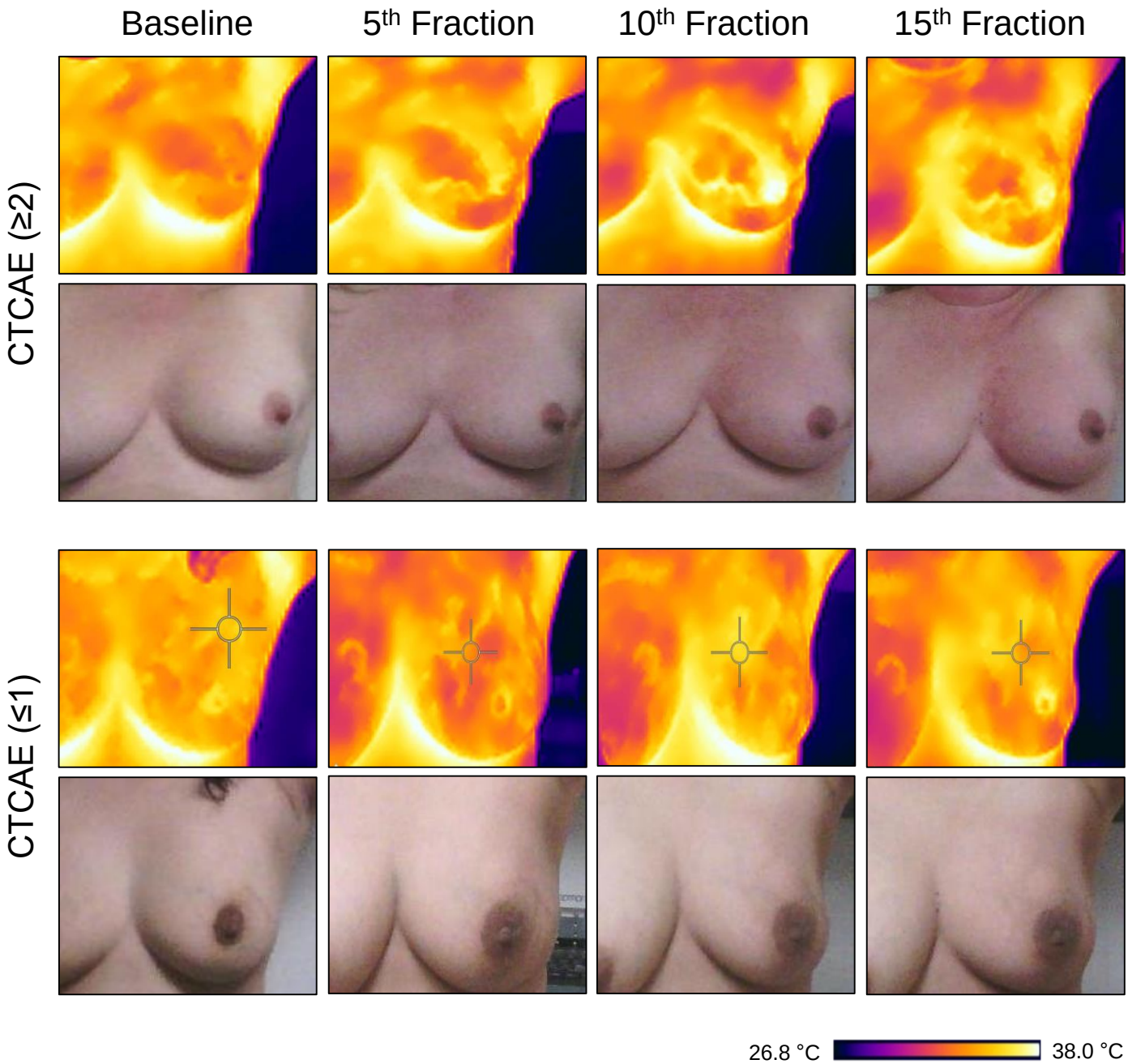


Experiment Three

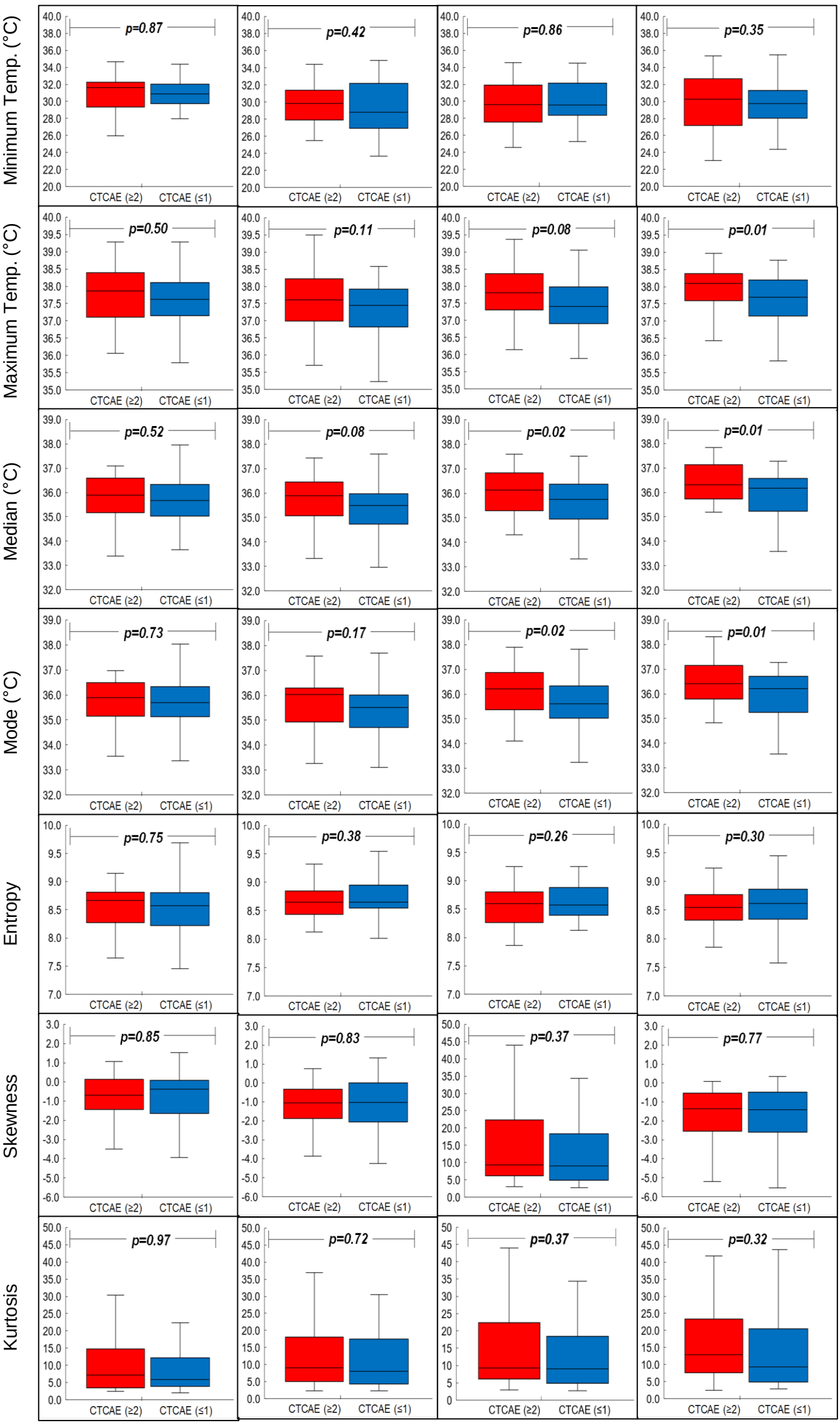
Optimal Feature Set:

Mean Temp(°C), GLCM-COR,
GLCM-ENE, GLCM-HOM, GLRLM-GLN



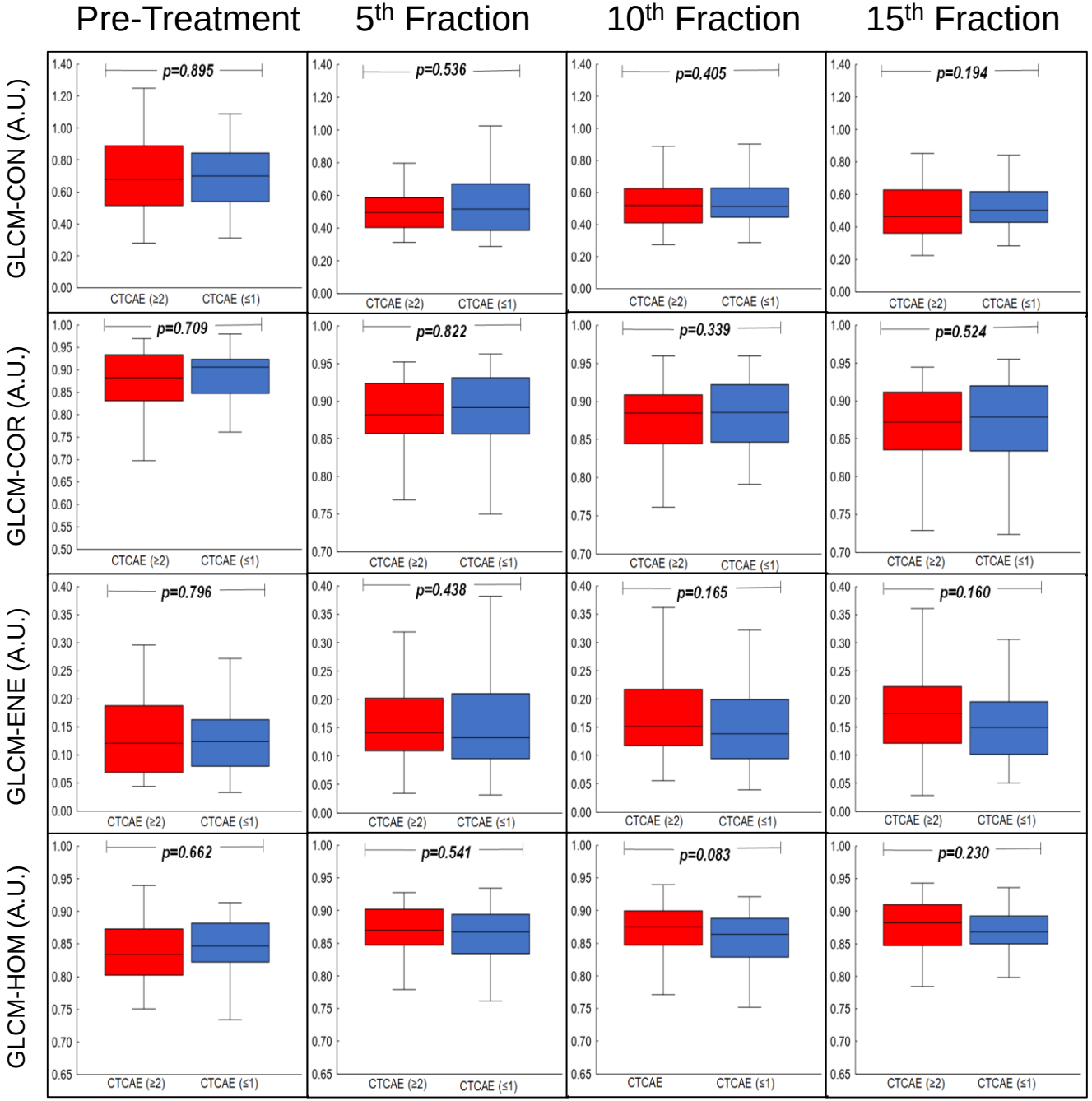


Supplementary Figure A.
Representative images of the skin reaction of the irradiated breast across RT treatment for a patient with an end-of-treatment score of CTCAE≥2 (top) and for a patient with a score of CTCAE≤1 (below). The CTCAE≥2 patient demonstrates noticeable dermatological changes and erythema which is most noticeable starting at the 10th fraction. A temperature scale bar is presented for the thermograms.



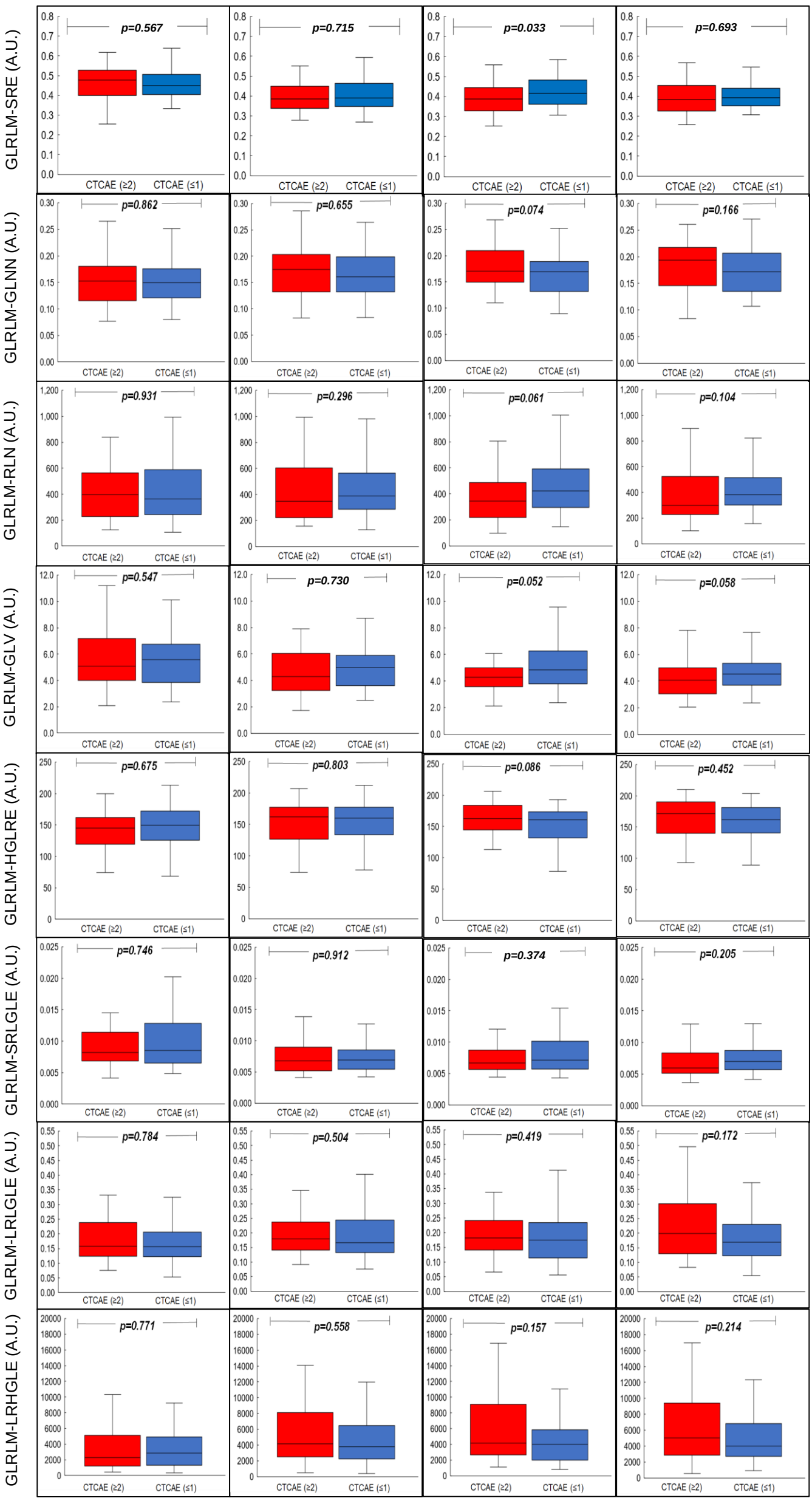
Supplementary Figure B

Temperature and first order features of the ipsilateral (irradiated) breast. Statistical significance was found for temperature between the patient groups at the 10th and 15th fractions. There was no statistically significant difference found between our patient groups for any of the first order features.



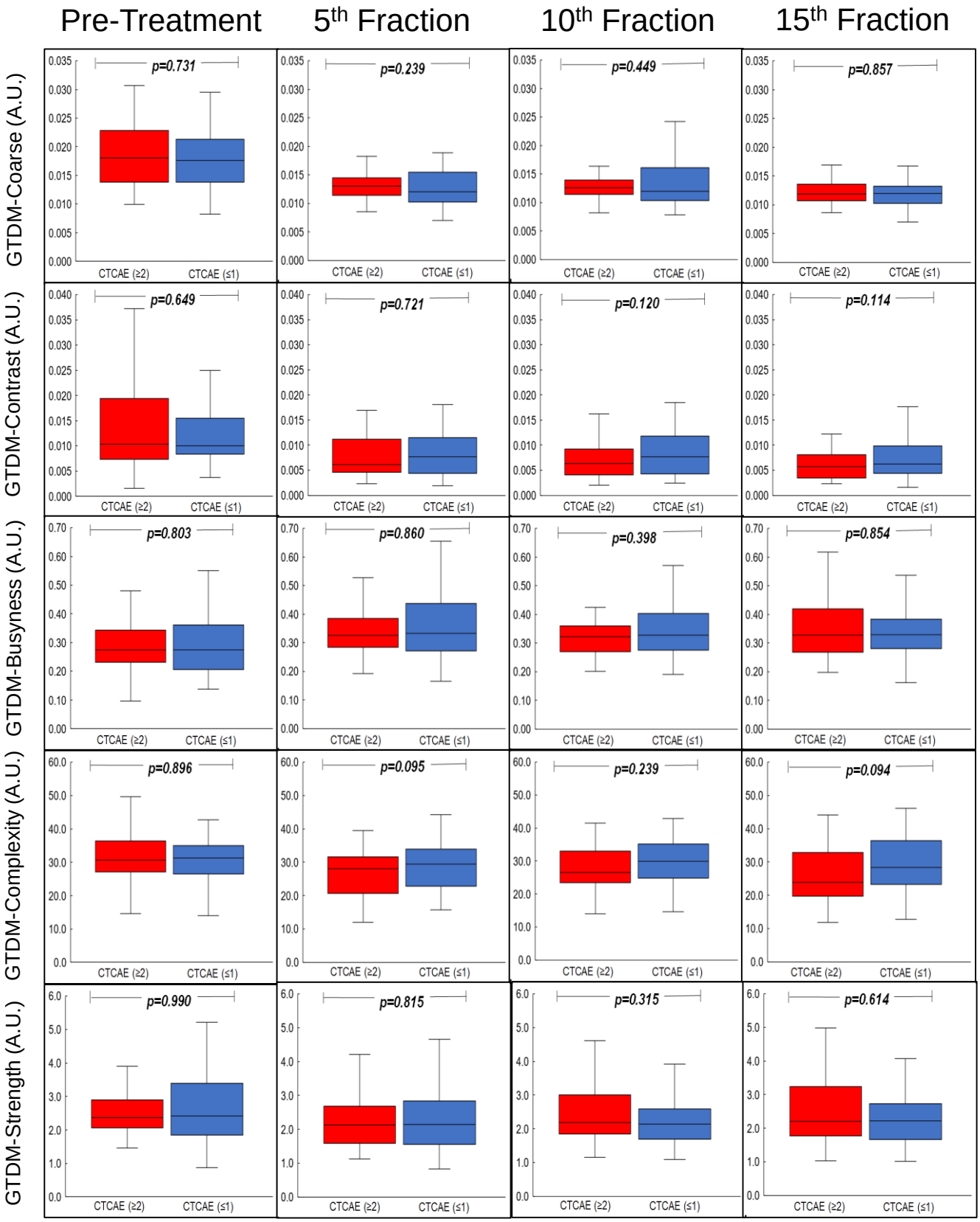
Supplementary Figure C

Temperature value distribution for GLCM features of the ipsilateral (irradiated) breast. There was no statistically significant difference found between our patient groups for any of the GLCM textural features.



Supplementary Figure D

Temperature value distribution for GLRLM features of the ipsilateral (irradiated) breast that demonstrated good predictive value. There was no statistically significant difference found between our patient groups for any of the GLRLM textural features, except for GLRLM-SRE (10th fraction).



Supplementary Figure E

Temperature value distribution for GTDM features of the ipsilateral (irradiated) breast. There was no statistically significant difference found between our patient groups for any of the GTDM textural features.