AI-DERIVED BODY COMPOSITION BIOMARKERS FROM CT IMAGING FOR PREDICTING CLINICAL RISK AND PATIENT OUTCOMES

SAI SRIYA POLURI, ARVIND CS, JORDAN, BHANU PRAKASH KN

Bioinformatics Institute
A*STAR BII

Tan Tock Seng HOSPITAL

STUDY DETAILS

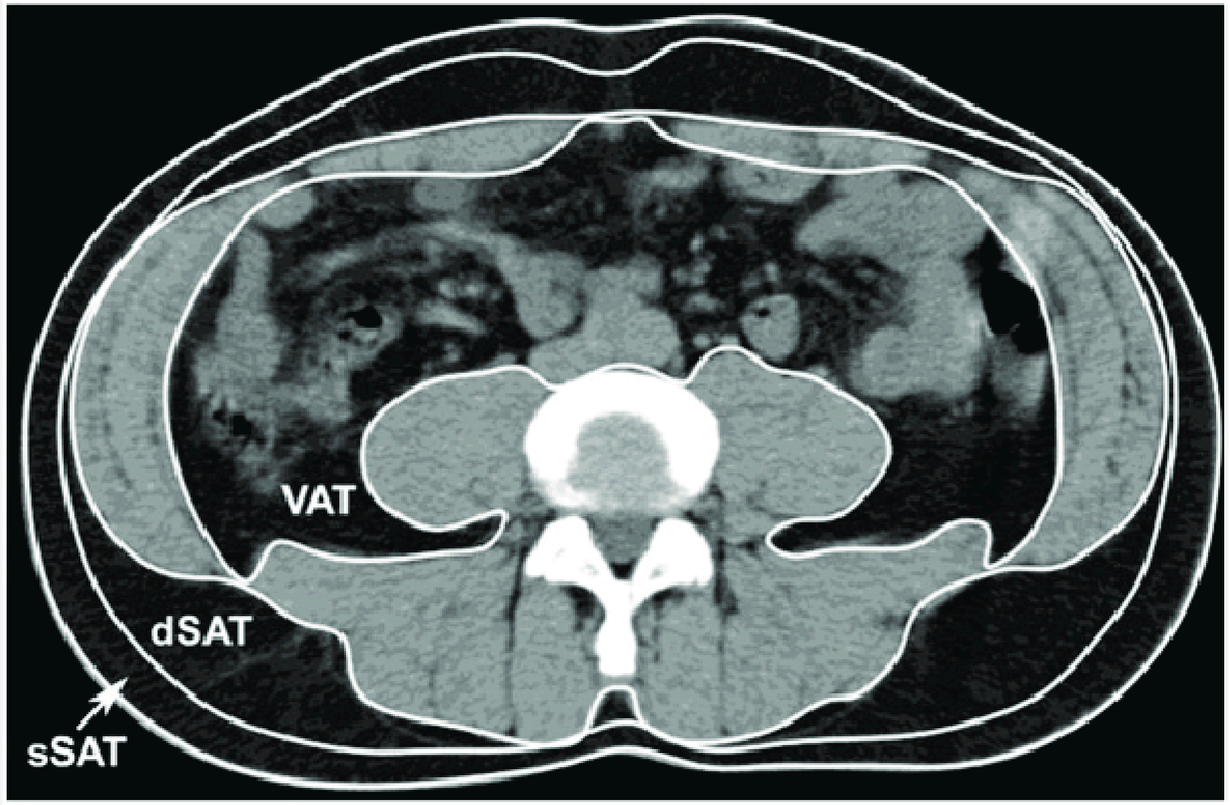
Dataset Description:

- Source: Tan Tock Seng Hospital (TTSH), Singapore
- Total Patients: 1,499
- Imaging Modalities: CT Scans
- Region of Interest: Abdomen Single Slice

Study Focus:

- Analyze body composition using CT scans.
- Focus on quantifying muscle, subcutaneous fat (SSAT), and visceral fat (VAT)
- Combining imaging-based body metrics and clinical data (e.g., Age, BMI, Pre-OP Parameters, Post-OP Parameters Chemotherapy, etc.) to find various insights

ABDOMEN



ABDOMENAL REGIONS

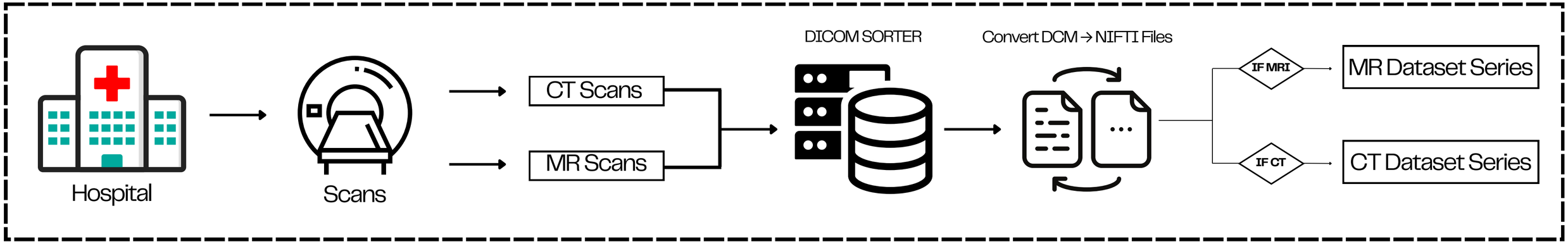
1. **SSAT**: Superficial Subcutaneous Adipose Tissue
2. **VAT**: Visceral Adipose Tissue
3. **DSAT**: Deep Subcutaneous Adipose Tissue
4. **MUSCLES**

These anatomical regions are critical for quantifying body composition, assessing metabolic health, and analyzing disease-linked changes in abdominal fat distribution.

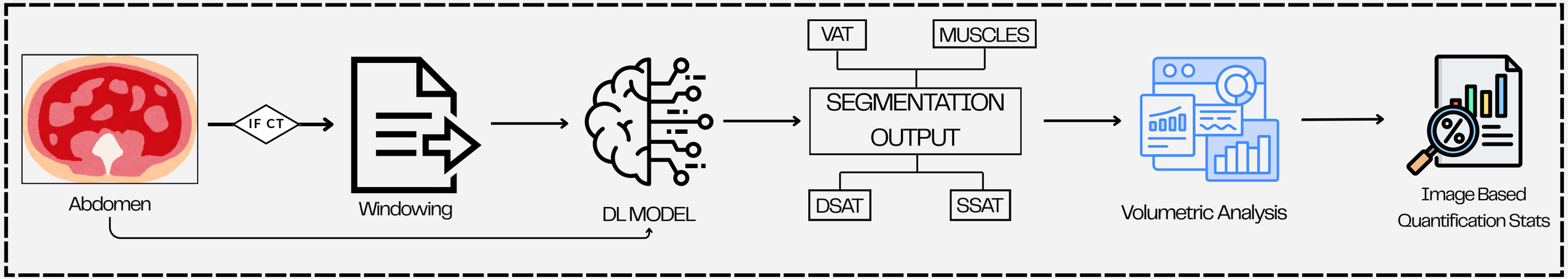
Shown above is a detailed cross-sectional diagram of the abdomen, outlining the anatomical compartments relevant to our study.

AI ENGINE ARCHITECTURE

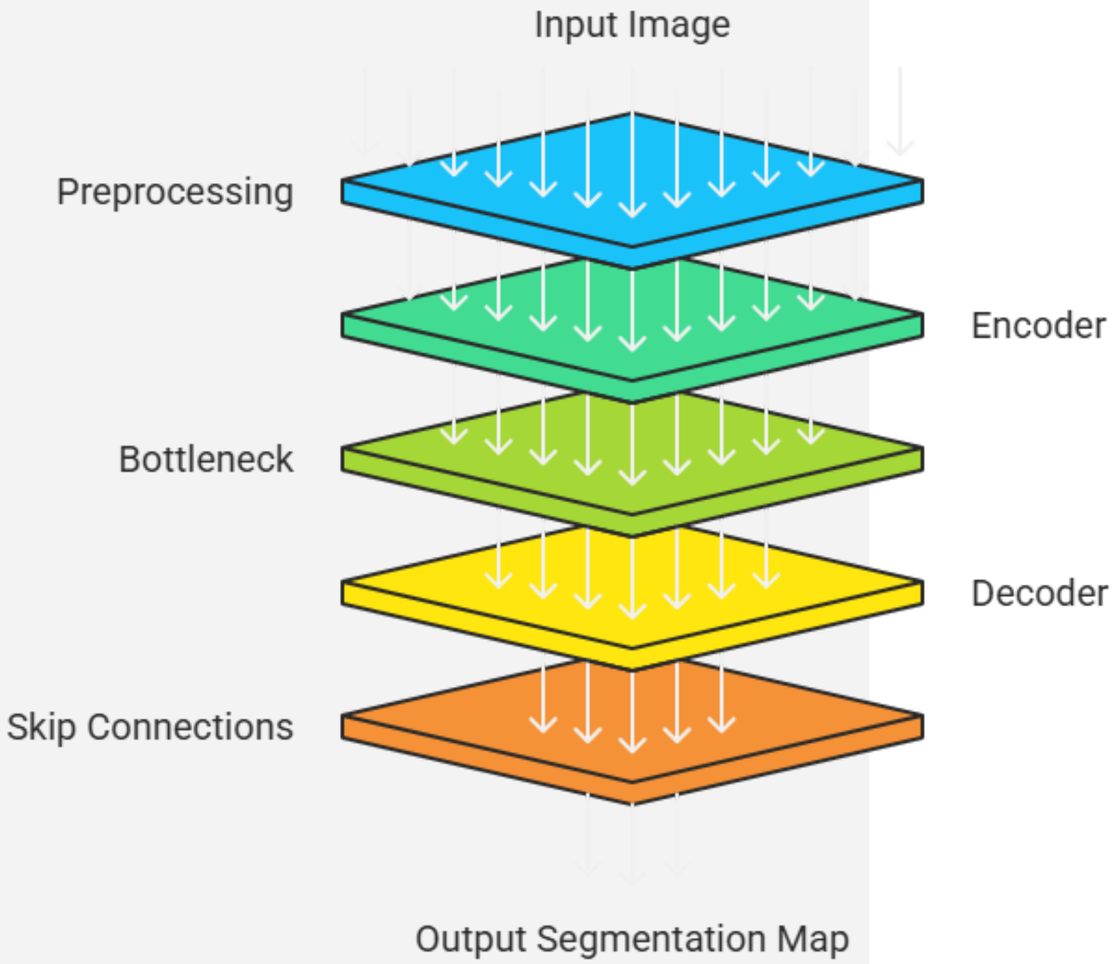
DATA PRE-PROCESSING



DEEP LEARNING MODEL



NNUNET

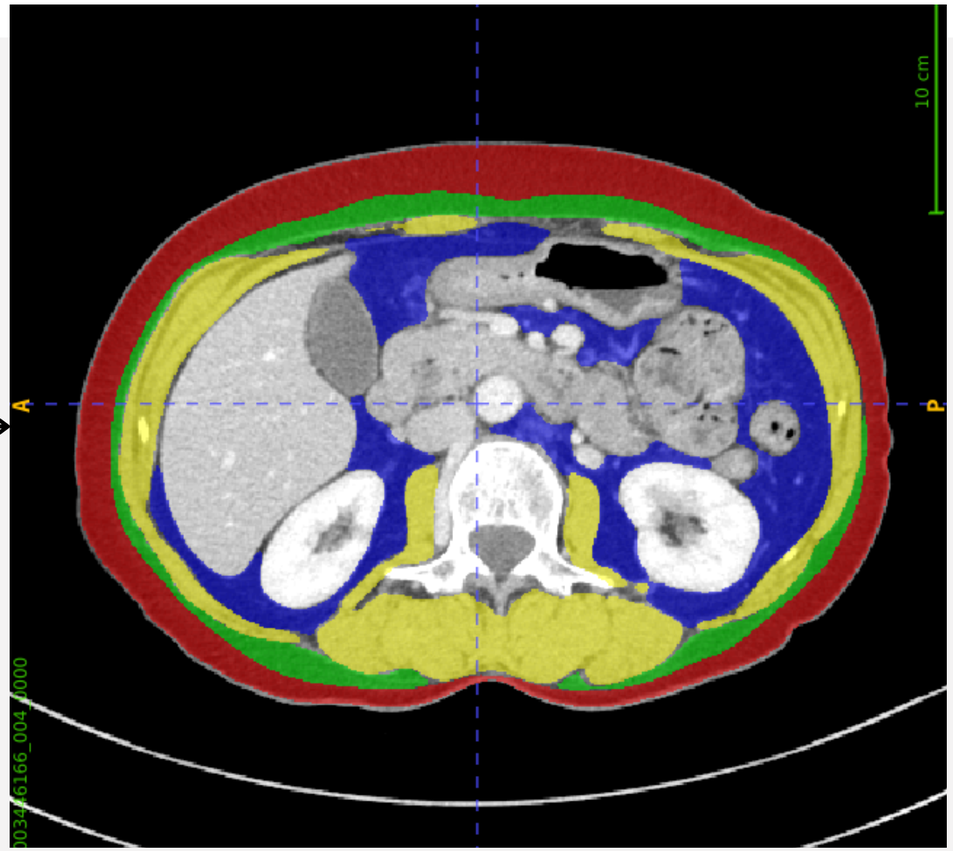


- nnU-Net (no-new-Net) builds upon the U-Net architecture but introduces a fully automated and self-configuring framework that adapts to any biomedical dataset.
- It dynamically adjusts preprocessing, network architecture (2D/3D U-Net variants), training schedules, and postprocessing steps based on dataset properties—eliminating the need for manual tuning.
- Despite using no novel architectural innovations, nnU-Net consistently achieves state-of-the-art performance by optimizing all pipeline components end-to-end for each task.

ABDOMEN SEGMENTATION RESULTS

RAW DATA

CT SCAN
INPUT

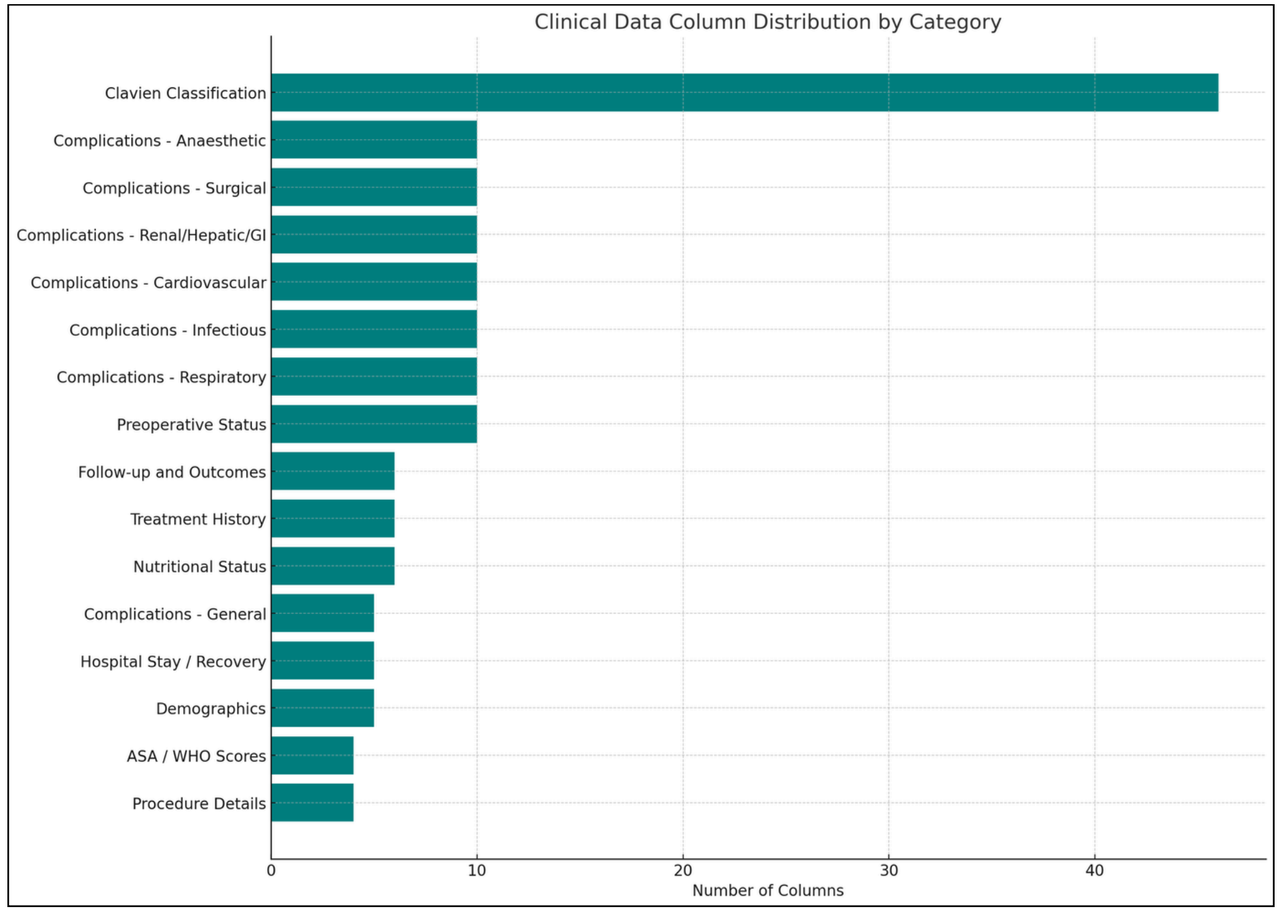


RESULTS DATA

SEGMENTED
OUTPUT

DATA ANALYSIS

CLINICAL DATA



IMAGING DATA

- SSAT: Superficial Subcutaneous Adipose Tissue
- VAT: Visceral Adipose Tissue
- DSAT: Deep Subcutaneous Adipose Tissue
- MUSCLES

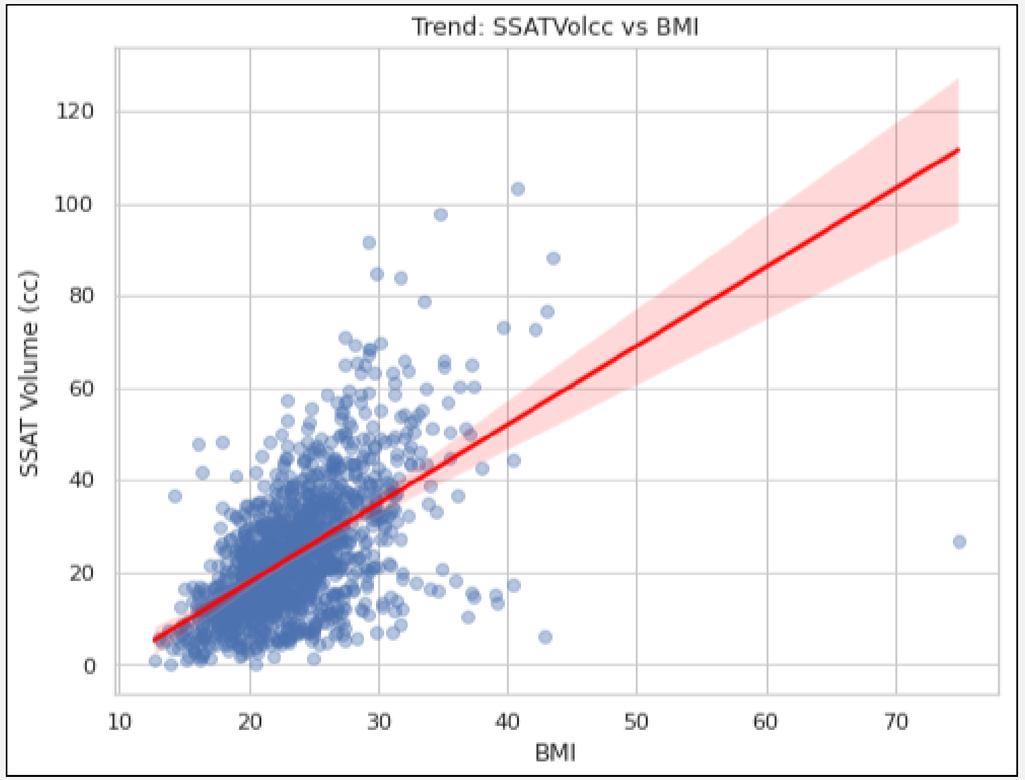
EXPLORATORY ANALYSIS

WHAT ARE WE FOCUSING ON?

- The Dataset consists of combined clinical and imaging dataset for a group of patients.
- Mainly looking at correlations between imaging and clinical data.
- Impact of Clinical Factors on Body Composition Metrics in Surgical Patients.
- The focus is on identifying trends, potential biomarkers, and clinical implications from body composition features such as muscle, SSAT, and VAT in relation to pre- and post-operative variables, chemotherapy status, and patient outcomes.

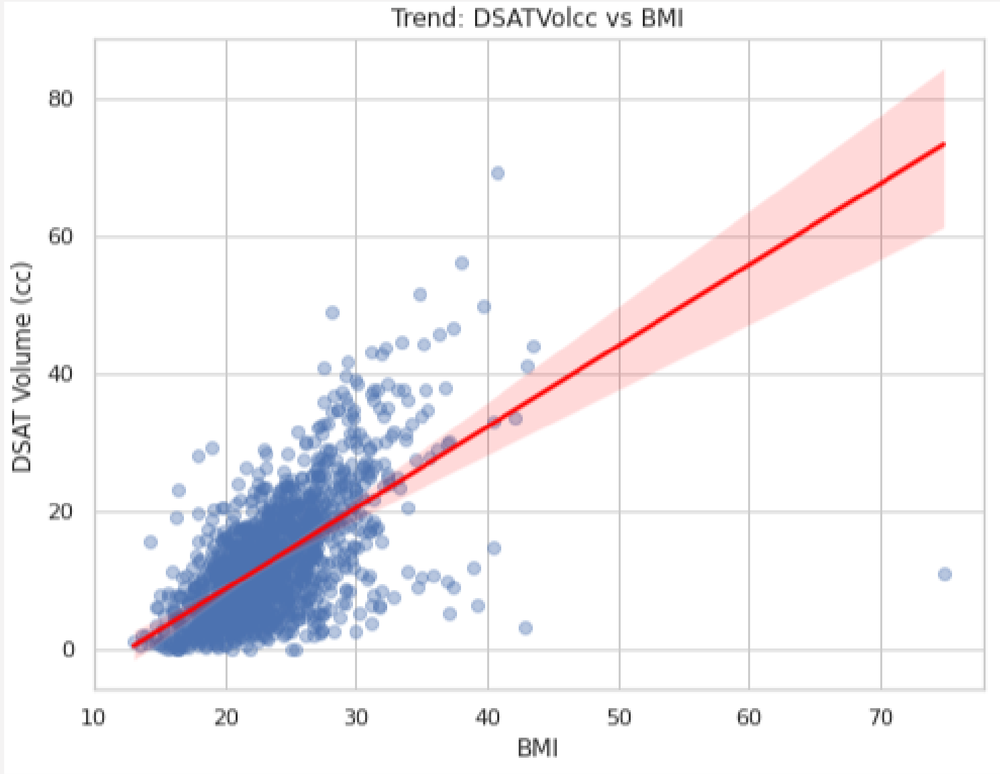
Relationship between BMI and SSAT Volume (cc)

- Strong linear relationship with BMI.
- Data points cluster tightly around the trendline, implying that SSAT increases predictably with BMI.
- Suggests that BMI is a reliable proxy for superficial subcutaneous abdominal fat.
- **Biomarker Insight:** SSAT could serve as a reliable imaging surrogate for general adiposity.



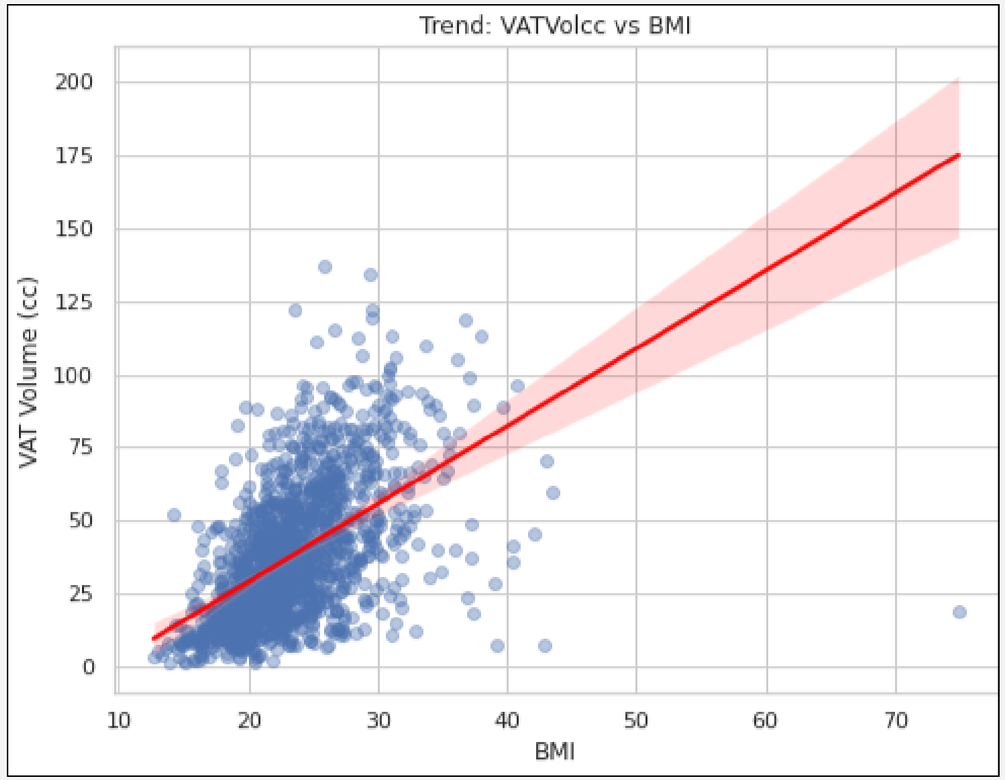
Relationship between BMI and DSAT Volume (cc)

- Moderate correlation compared to VAT, with a clear upward trend.
- DSAT increases with BMI, but shows greater individual variability, especially at lower BMI levels.
- Suggests that BMI partially reflects subcutaneous fat accumulation, though less reliably than visceral fat.
- **Biomarker Insight:** DSAT may contribute to metabolic risk independently and highlights the need for imaging-based fat profiling beyond BMI alone.



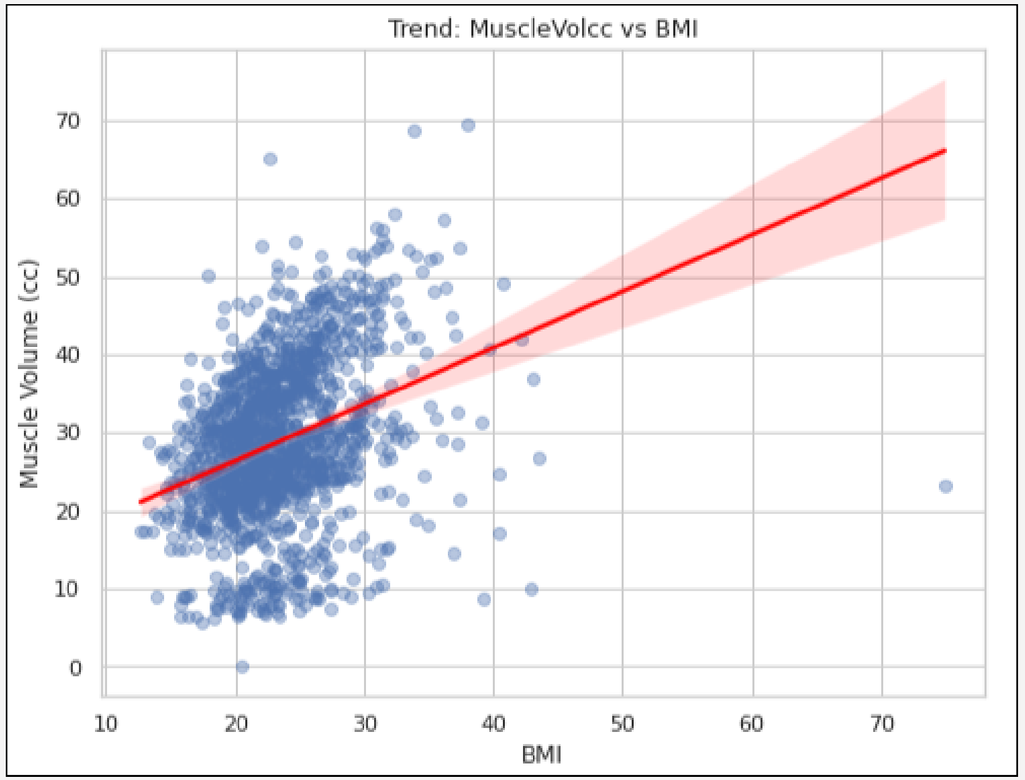
Relationship between BMI and VAT Volume (cc)

- Strongest correlation of the three metrics.
- VAT rises sharply with BMI and exhibits less variance than muscle volume.
- Indicates that BMI is a good indicator of visceral adiposity, which is a key cardiometabolic risk factor.
- **Biomarker Insight:** VAT volume is a key marker for metabolic syndrome and cardiovascular risk.

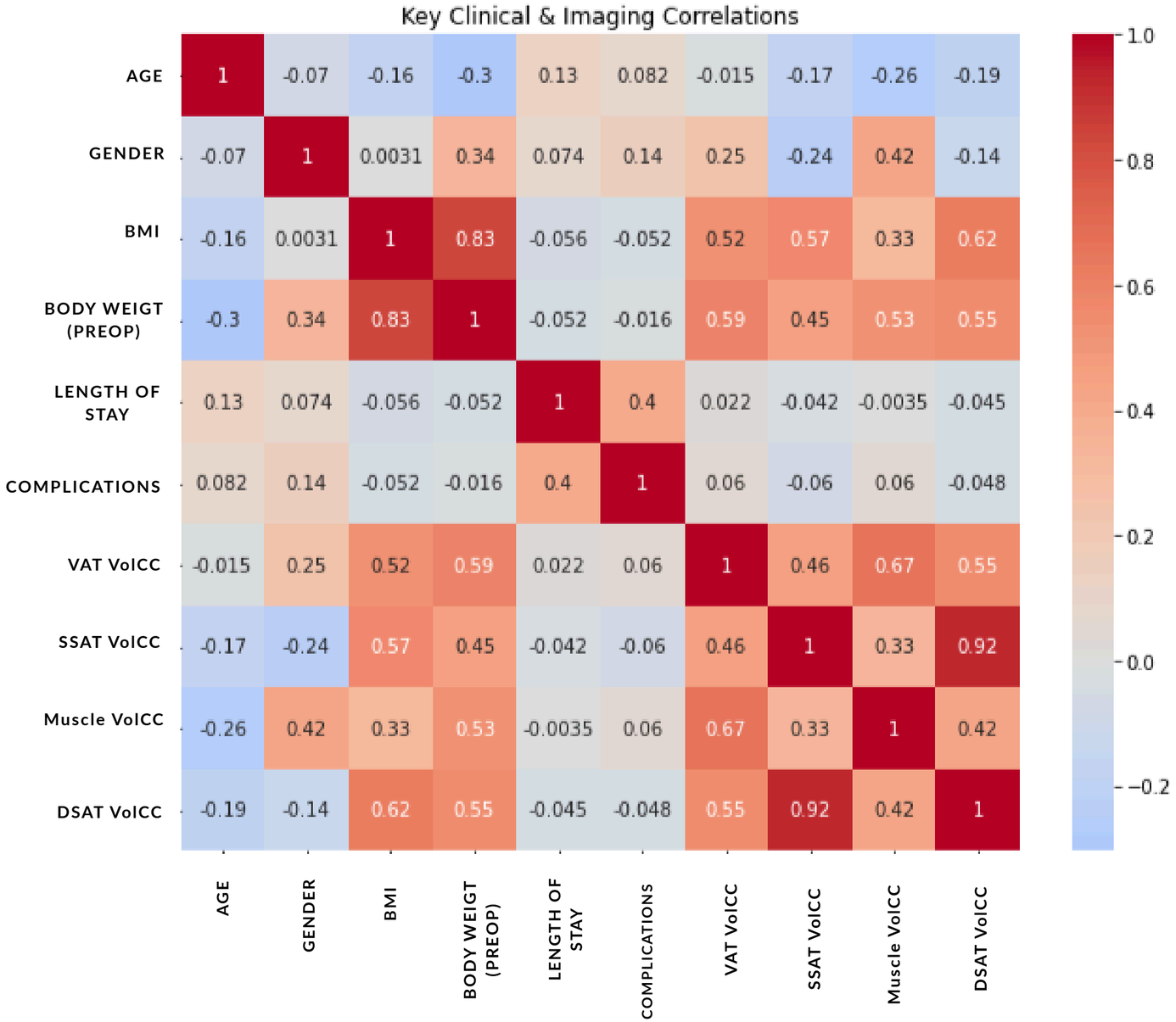


Relationship between BMI and Muscle Volume (cc)

- Moderate positive correlation between BMI and abdominal muscle volume.
- However, wider variance is seen across individuals with similar BMI (especially in 20–30 range), indicating that BMI alone is insufficient to estimate muscle mass.
- Some high-BMI individuals still show low muscle volume, which may reflect sarcopenic obesity.
- **Biomarker Insight:** Muscle volume must be considered directly—especially in overweight patients.

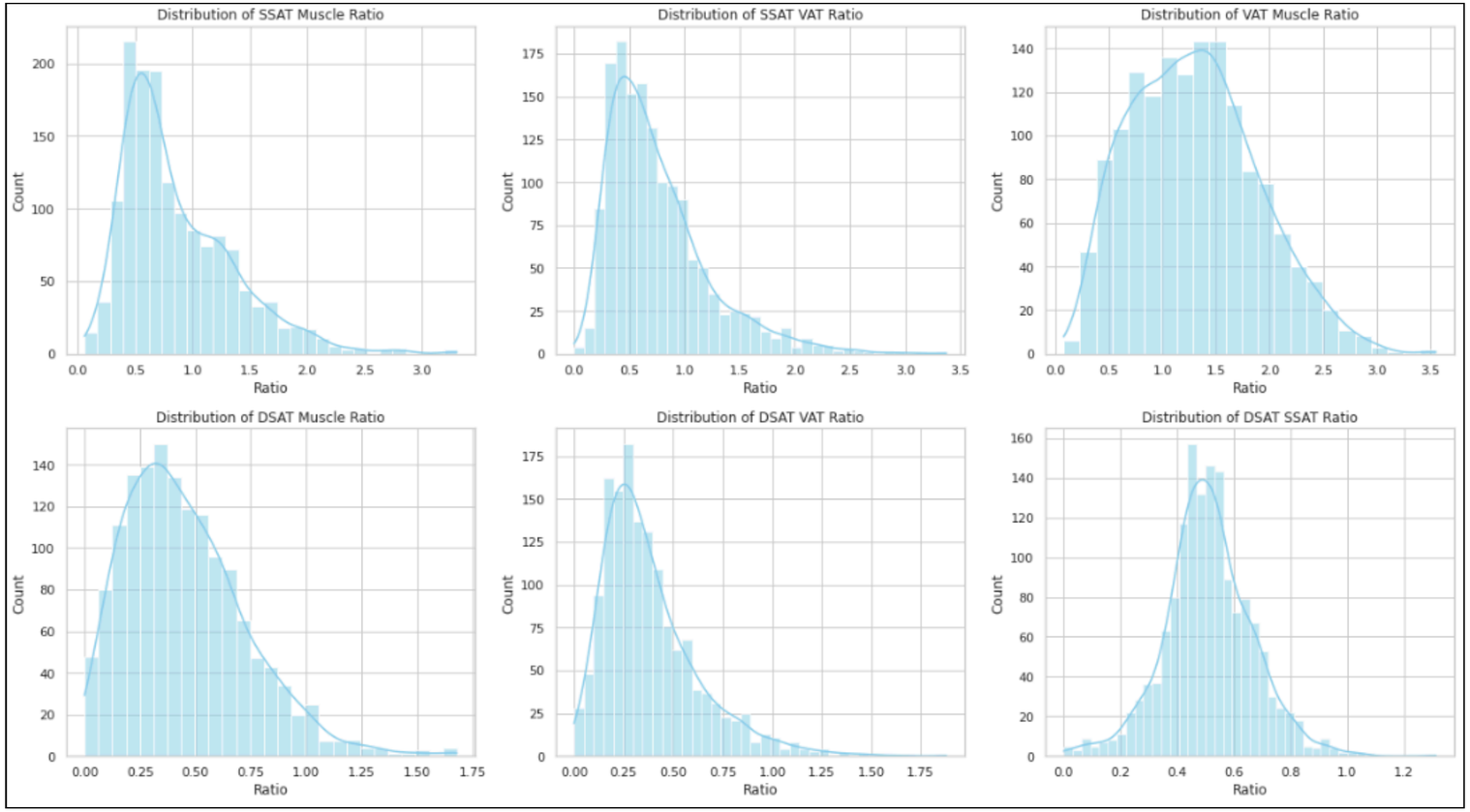


CORRELATION HEATMAP



- Muscle mass decreases with age (−0.26) and is higher in males (0.42), consistent with known physiology.
- BMI and preoperative weight show strong positive correlations with all fat volumes (VAT, SSAT, DSAT) and muscle volume, reinforcing body habitus as a primary imaging driver.
- DSAT volume has the strongest correlation with SSAT (0.92) and also correlates with BMI (0.62) and weight (0.55), suggesting DSAT scales closely with subcutaneous fat stores.
- Complications and length of stay show weak correlations with body composition metrics (< 0.1), implying limited direct predictive value in isolation.
- VAT and SSAT remain moderately correlated (0.46), and both associate with MuscleVolcc (0.33–0.42), indicating overall systemic fat-muscle interplay.
- **Biomarker Insight: DSAT volume closely mirrors SSAT (r = 0.92) and tracks with BMI, making it a strong imaging biomarker for overall subcutaneous fat burden.**

Fat-to-Muscle Ratio Analysis

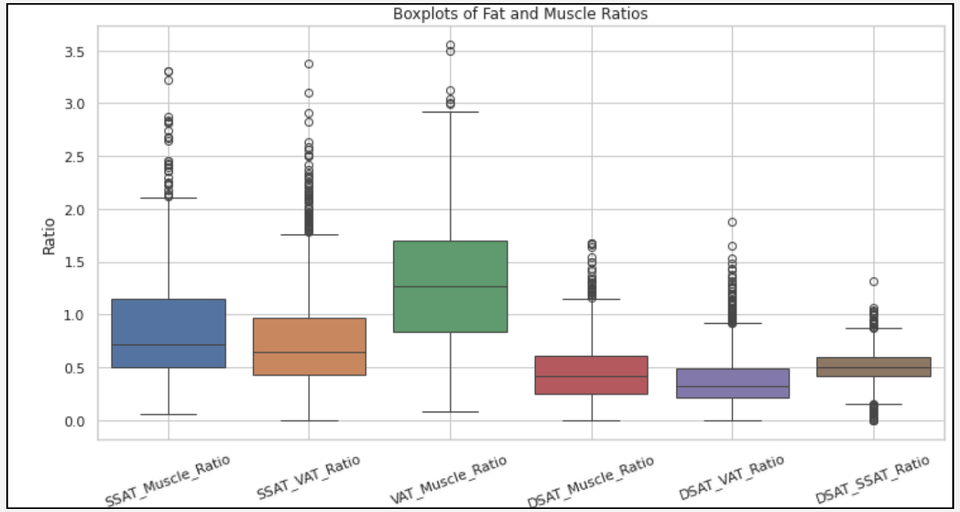


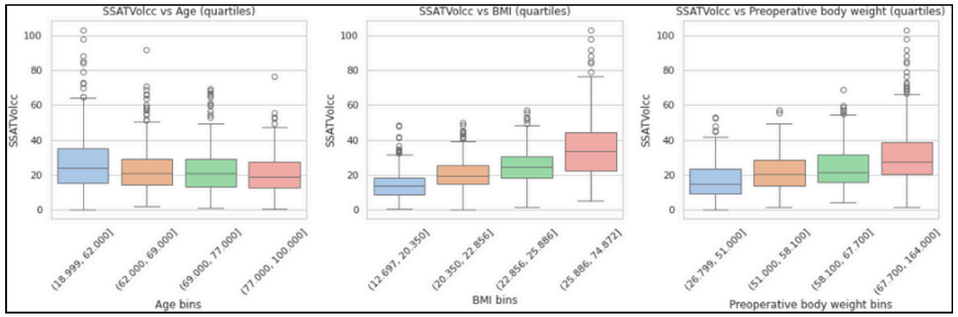
- Most ratios are right-skewed, indicating that a subset of patients has disproportionately high fat relative to muscle, which may signal elevated metabolic risk.

- The boxplot reveals outliers with extreme fat dominance — potential candidates for closer clinical evaluation or stratification in predictive modeling.

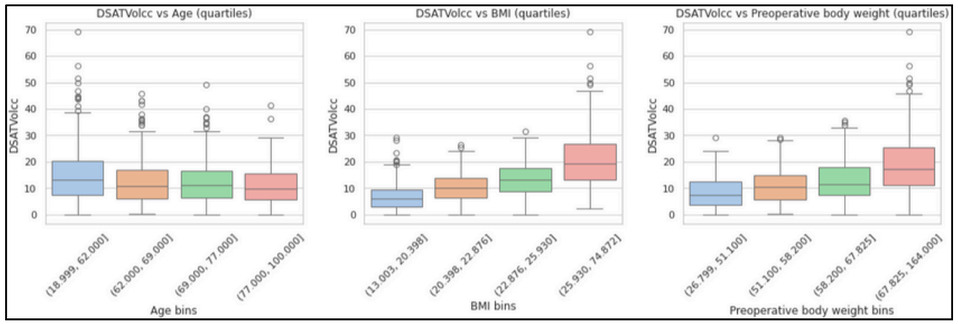
- SSAT and VAT show the highest fat-to-muscle ratios, with VAT-Muscle Ratio having the widest spread, indicating greater inter-individual variability in visceral fat accumulation.

- DSAT ratios are consistently lower and tighter, especially DSAT-SSAT Ratio, suggesting DSAT is a smaller but stable fat compartment.

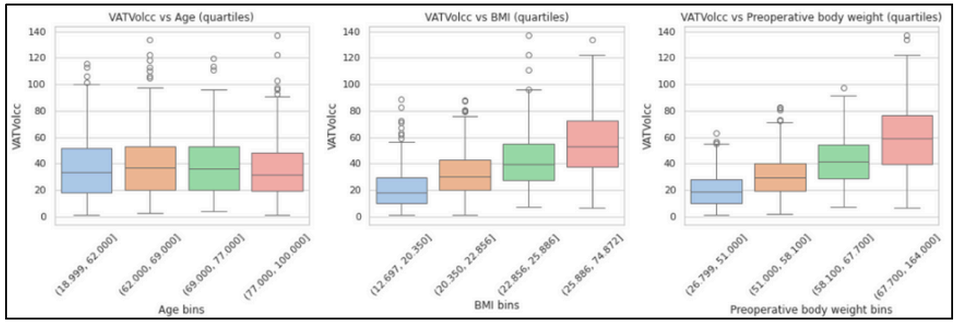




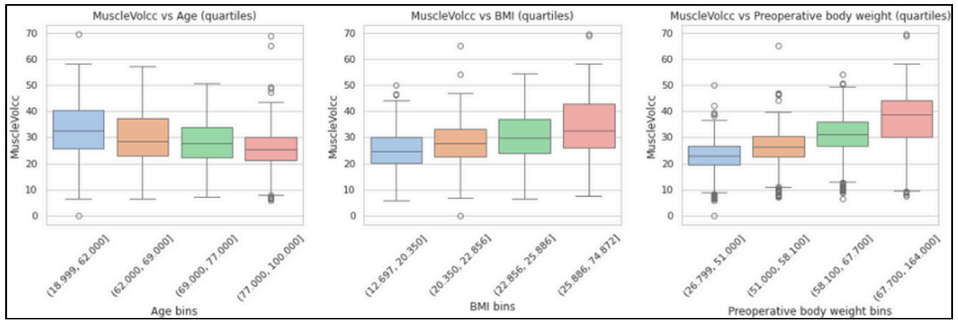
SSAT



DSAT



VAT



Muscles

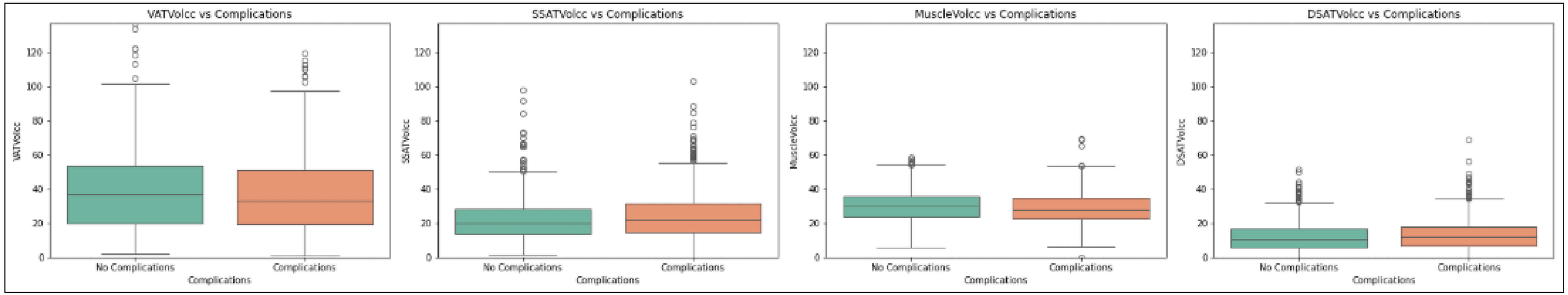
IMAGING FEATURES VS PRE-OP VARIABLES

Metric	↑ with BMI	↑ with Weight	Changes with Age
VATVolcc	Strong	Strong	Mild ↓ / Flat
SSATVolcc	Strong	Strong	Mild ↓
MuscleVolcc	Medium, but not as steep as fat metrics	Strong	Declines clearly
DSATVolcc	Medium – less steep than VAT/SSAT	Medium	Slight decline / stable

Biomarker Insight:

- VAT and SSAT volumes consistently increase with BMI and weight, highlighting them as reliable biomarkers of adiposity.
- Muscle volume increases with weight but declines with age, reflecting sarcopenic trends.
- DSAT shows moderate sensitivity to BMI and weight, suggesting it can serve as a supportive marker of subcutaneous fat burden, especially when combined with SSAT.

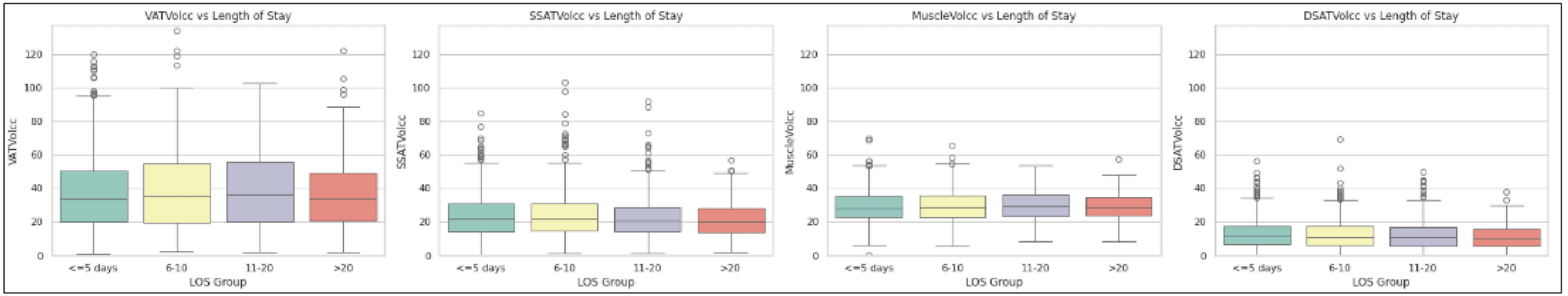
IMAGING FEATURES VS POST-OP VARIABLES



Feature	Observation	Insight
VATVolcc	Median slightly higher in "No Complications", but the distributions overlap	Visceral fat may not directly predict complications in this cohort.
SSATVolcc	Very similar distributions for both groups	Subcutaneous fat appears neutral with respect to complication risk.
MuscleVolcc	Slightly higher in No Complications group	Lower muscle mass may be weakly linked to increased complication risk, per sarcopenia data.
DSATVolcc	Slight downward shift in complications group	Reduced DSAT may have a weak link with complications, but not a strong predictive marker.

Biomarker Insight: Lower muscle and DSAT volumes may weakly signal higher complication risk, while VAT and SSAT appear less predictive.

IMAGING FEATURES VS POST-OP VARIABLES

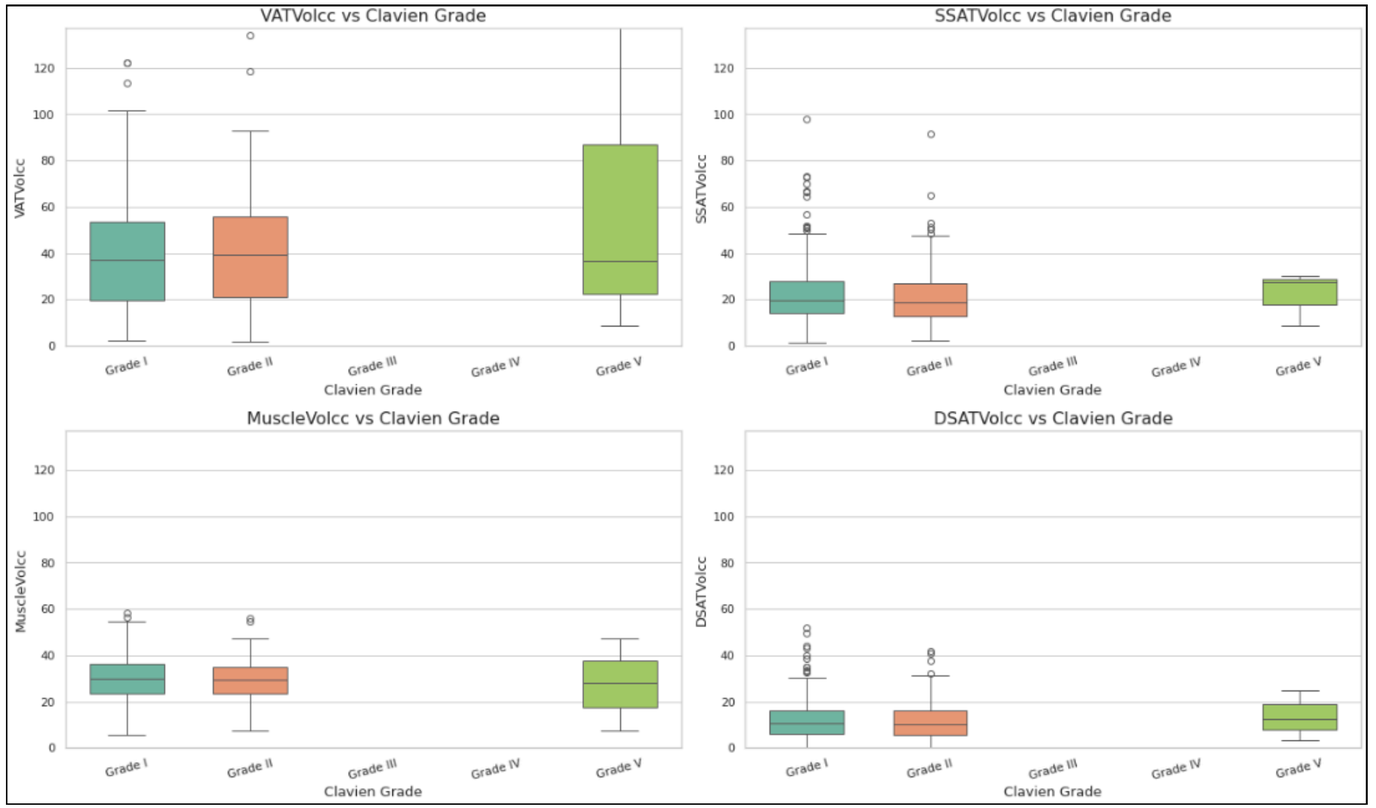


Feature	Observation	Insight
VATVolcc	Highest spread in all LOS groups; median slightly decreases with longer stay	Possibly confounded — **higher VAT doesn't always mean longer stay**. Mobility/age could affect this.
SSATVolcc	Very similar medians across LOS groups	Subcutaneous fat is **not predictive** of hospital stay duration.
MuscleVolcc	Slight upward trend with LOS	Possibly due to **younger patients needing longer recovery** for complex surgeries.
DSATVolcc	Median fairly flat across LOS groups	**DSAT appears stable** across LOS durations, **not strongly tied to recovery time**.

Biomarker Insight: DSAT and muscle volume slightly decrease with longer stays, suggesting possible association with recovery pace. VAT and SSAT remain largely stable, indicating limited predictive value for LOS.

IMAGING FEATURES VS POST-OP VARIABLES

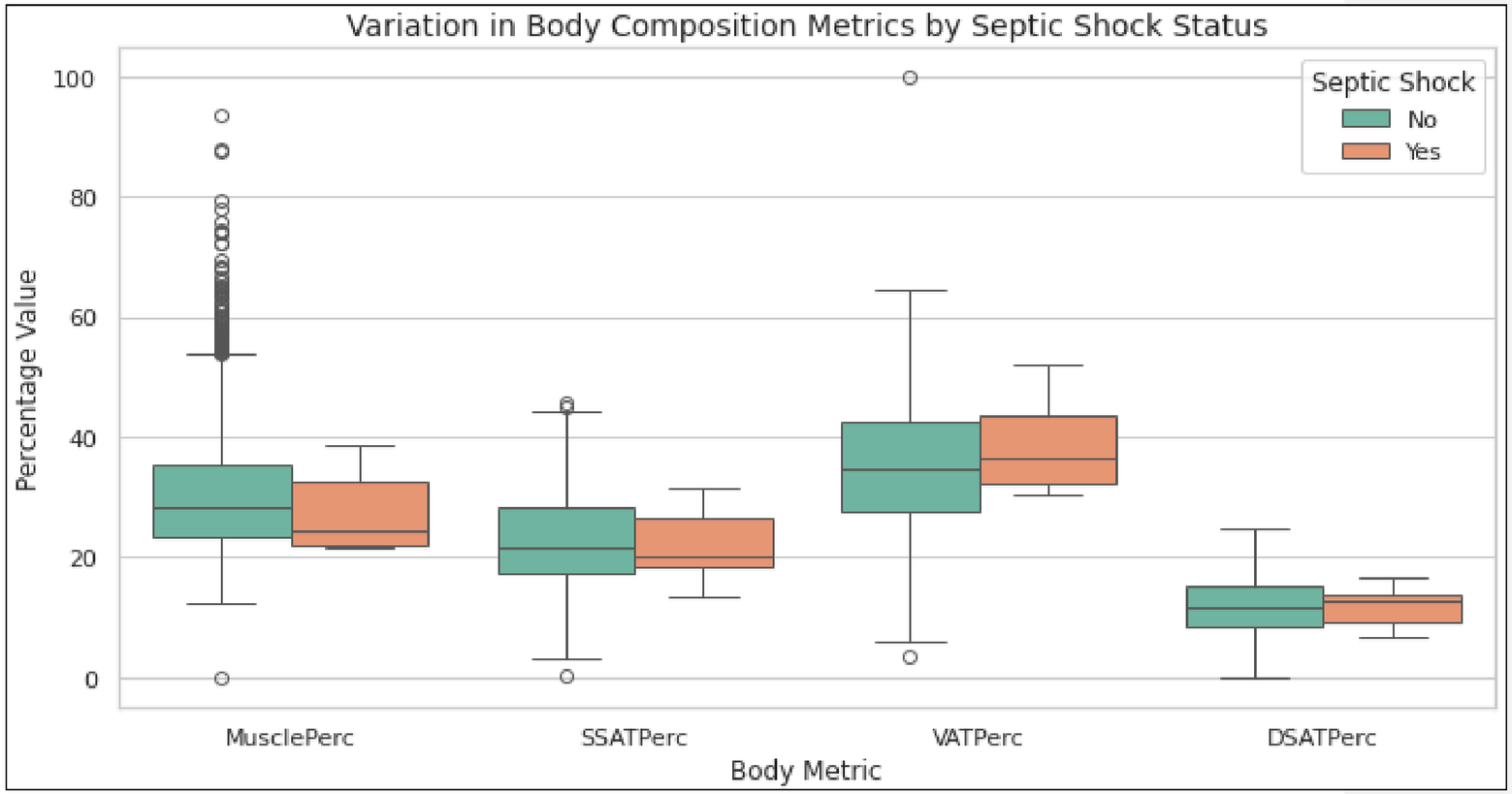
- **Clavien:** A system used to grade the severity of surgical complication
- VAT volume shows a noticeable rise in patients with Grade V (death) complications.
- SSAT shows minimal variation across grades.
- Muscle volume appears elevated in Grade V, potentially due to more aggressive interventions in younger/fitter patients.
- DSATVolcc is noticeably higher in patients with Grade V complications, suggesting that deeper subcutaneous adipose tissue may be associated with more severe postoperative outcomes.



Biomarker Insight: Higher VAT, SSAT, DSAT, and Muscle volumes appear elevated in Grade V complications, suggesting that extreme body composition values may be linked to severe adverse outcomes — though patterns are inconsistent across lower grades.

Clavien-Dindo Grade
Grade I–II: Mild complications
Grade III–IV: Moderate to severe
Grade V: Death

Variation in Body Composition Metrics by Septic Shock Status



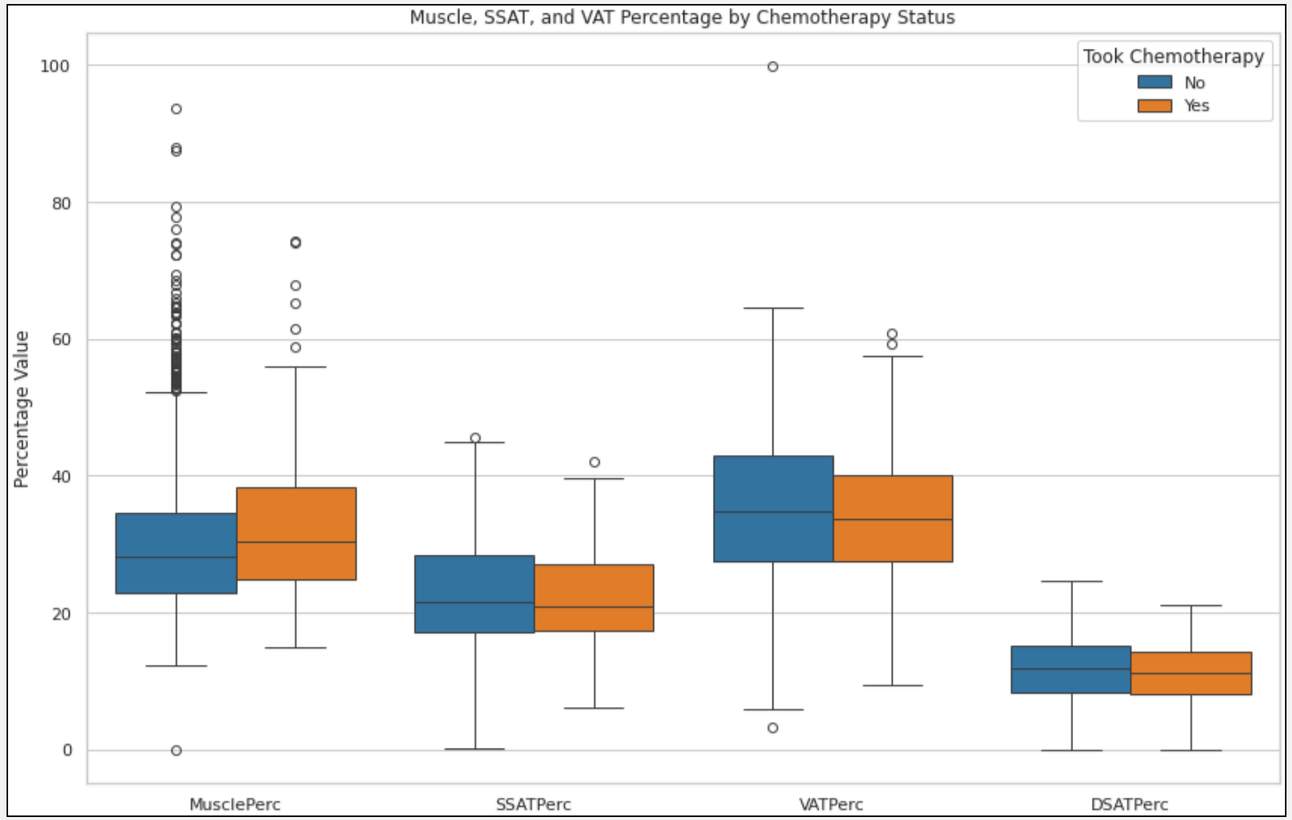
- Septic shock patients show lower muscle % and higher VAT %, indicating a link between frailty, visceral adiposity, and infection severity.
- SSAT % differences are minimal, suggesting it may be less predictive in this context.
- DSAT % is slightly higher in septic shock patients, but the overlap is broad—indicating a possible weak association with infection risk, though not a strong standalone predictor.

Biomarker Insight: Low muscle mass and high visceral fat are strong body composition markers linked to septic shock, while DSAT% shows limited differentiation and weaker predictive potential.

HOW CHEMOTHERAPY AFFECTS ?

HOW CHEMOTHERAPY IS AFFECTING?

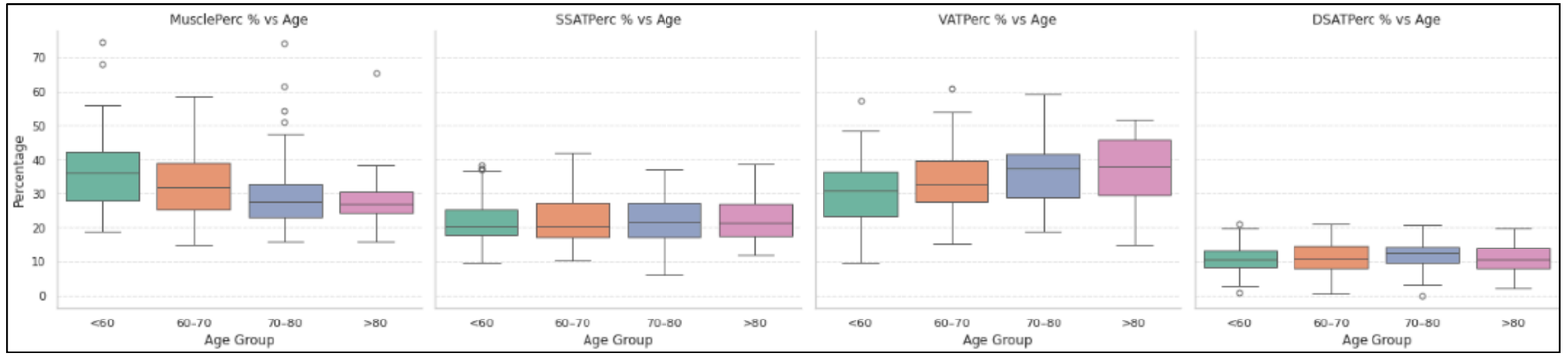
- Muscle % is slightly higher in chemotherapy patients — possibly due to more aggressive nutritional or physical therapy protocols post-treatment.
- VAT % shows a modest decline in chemotherapy patients — suggesting possible metabolic or cachectic effects.
- SSAT % and DSAT % differences are minimal — subcutaneous fat may remain stable across treatment groups.



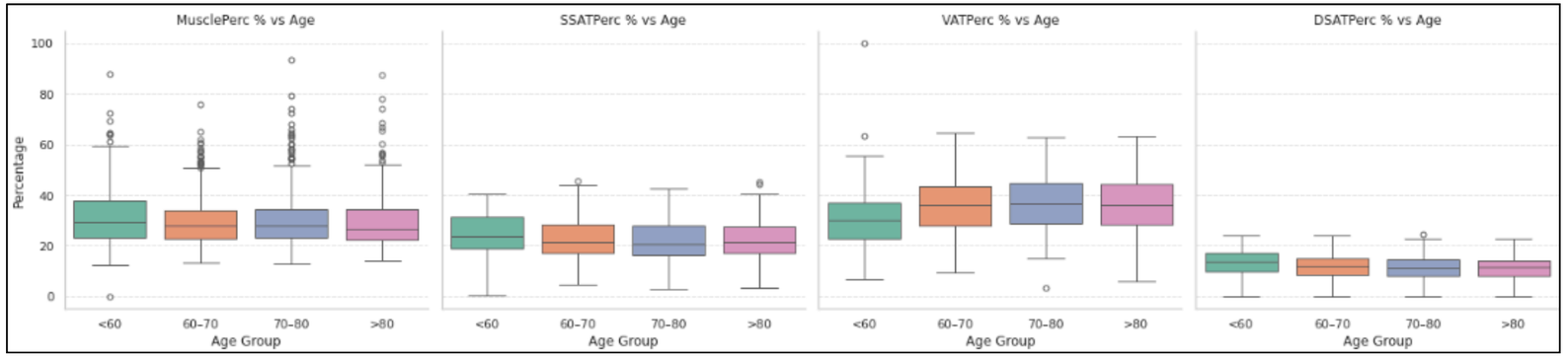
Biomarker Insight: Chemotherapy accelerates sarcopenia → need for monitoring muscle volume loss.

COMPARISON OF BODY COMPOSITION BY AGE & CHEMOTHERAPY STATUS

- Muscle % declines more steeply with age in chemotherapy patients, suggesting accelerated sarcopenia.
- SSAT % shows mild age-related increase, more evident in the chemo group.
- VAT % increases consistently with age, with chemo patients exhibiting higher visceral fat levels, especially in the >80 age group.
- DSAT% declines mildly with age in chemotherapy patients. In contrast, non-chemo individuals maintain more consistent DSAT%, suggesting preserved peripheral fat with age.



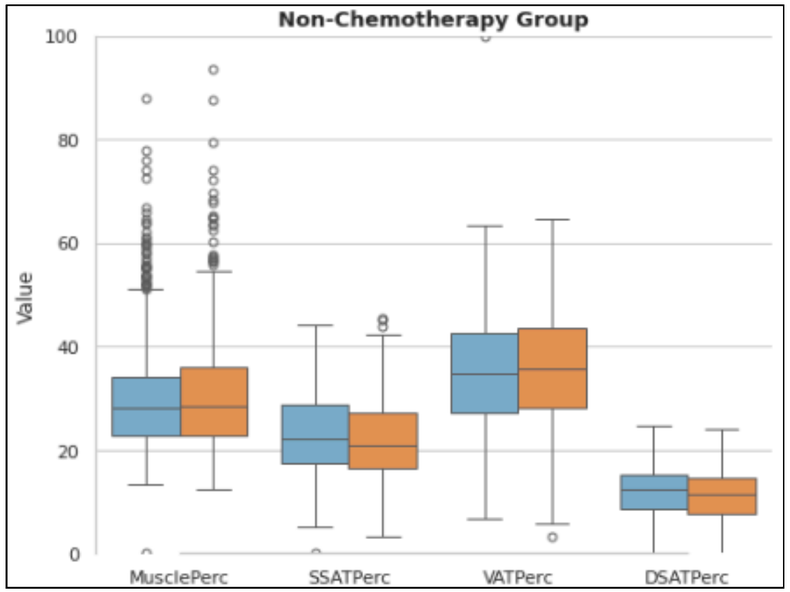
CHEMO GROUP

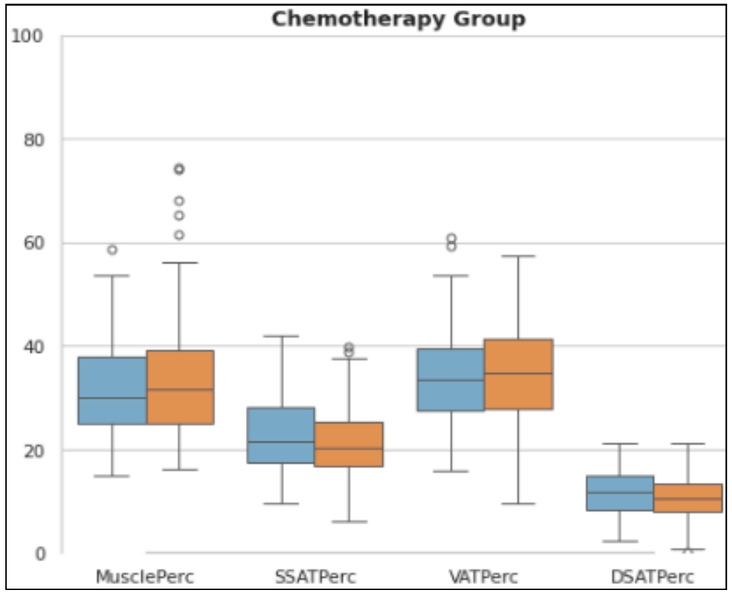


NON - CHEMO GROUP

Biomarker Insight: Chemo patients show steeper age-related loss in Muscle% and DSAT%, indicating treatment-linked frailty. Non-chemo group shows more stable body composition.

IMPACT OF CHEMOTHERAPY ON BODY COMPOSITION & HOSPITAL STAY



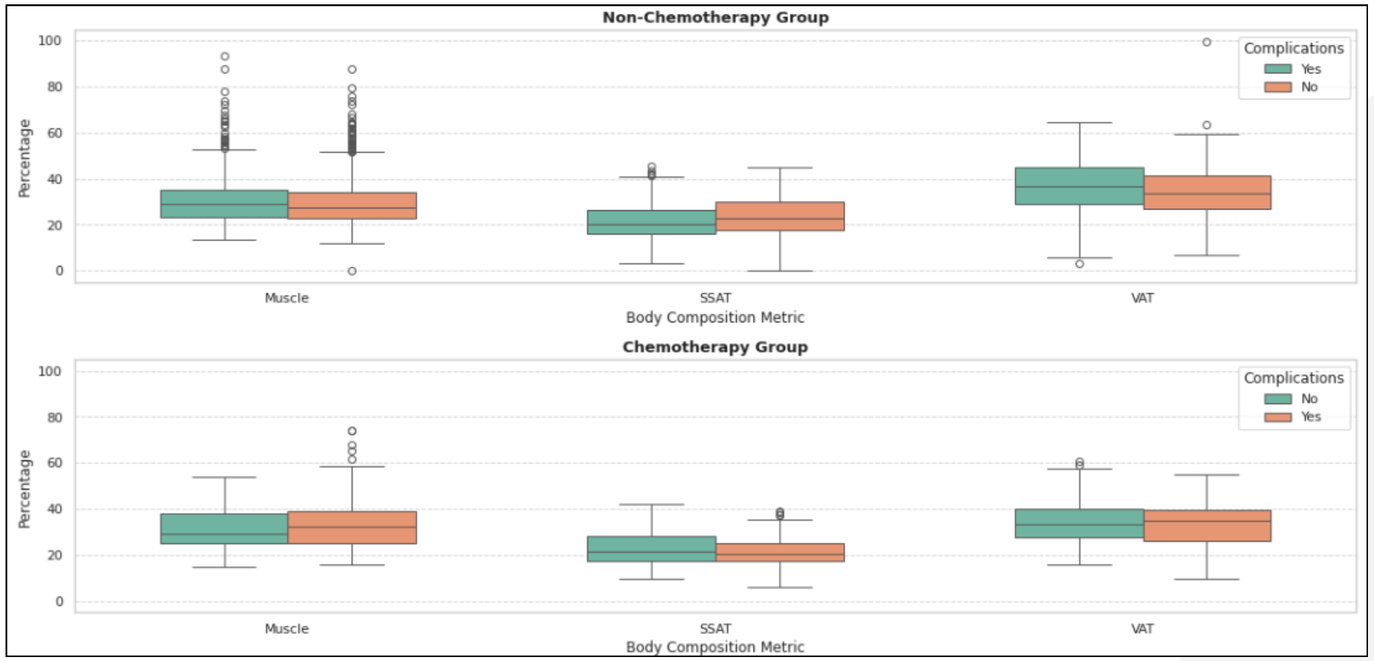


Feature	Non-Chemotherapy Patients	Chemotherapy Patients
Muscle %	Similar across short and long stay	Slightly higher in **long stay** group
SSAT %	Stable across stay durations	**Reduced in long stay**, indicating fat loss or malnutrition
VAT %	Slight increase in long stay	Noticeable rise in **long stay** group, possibly due to inflammation or metabolic stress
DSAT %	Relatively stable across stay durations	Declines in long stay group, suggesting tissue depletion

Biomarker Insight: Decline in DSAT% among long-stay chemotherapy patients may indicate deep fat loss linked to catabolic stress or malnutrition.

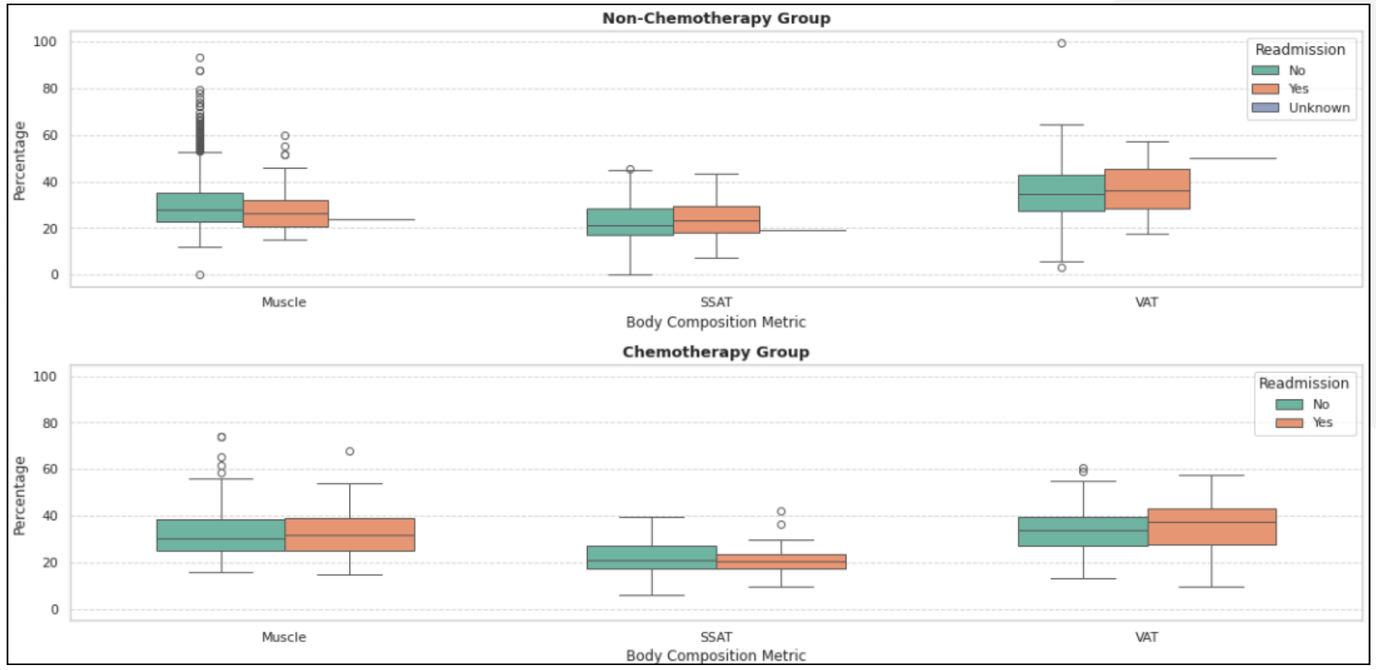
Chemotherapy patients show greater variability and tissue loss, especially in subcutaneous fat, with prolonged hospital stays.

COMPLICATIONS



Higher VAT % and lower muscle % are associated with greater complication rates, especially in the non-chemo group. SSAT shows minimal variation. These findings suggest that body composition—particularly visceral fat —may influence surgical risk.

READMISSION

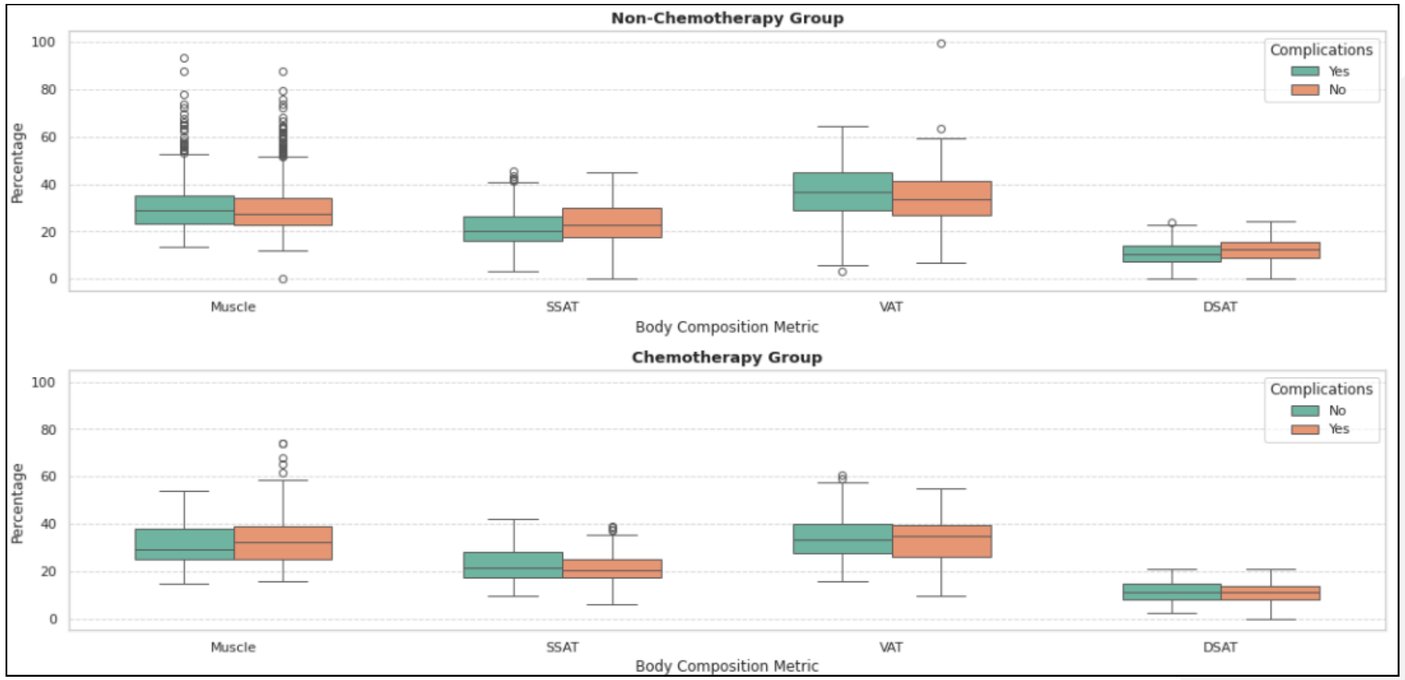


Readmission is more common in patients with higher VAT %, particularly in the non-chemotherapy group.

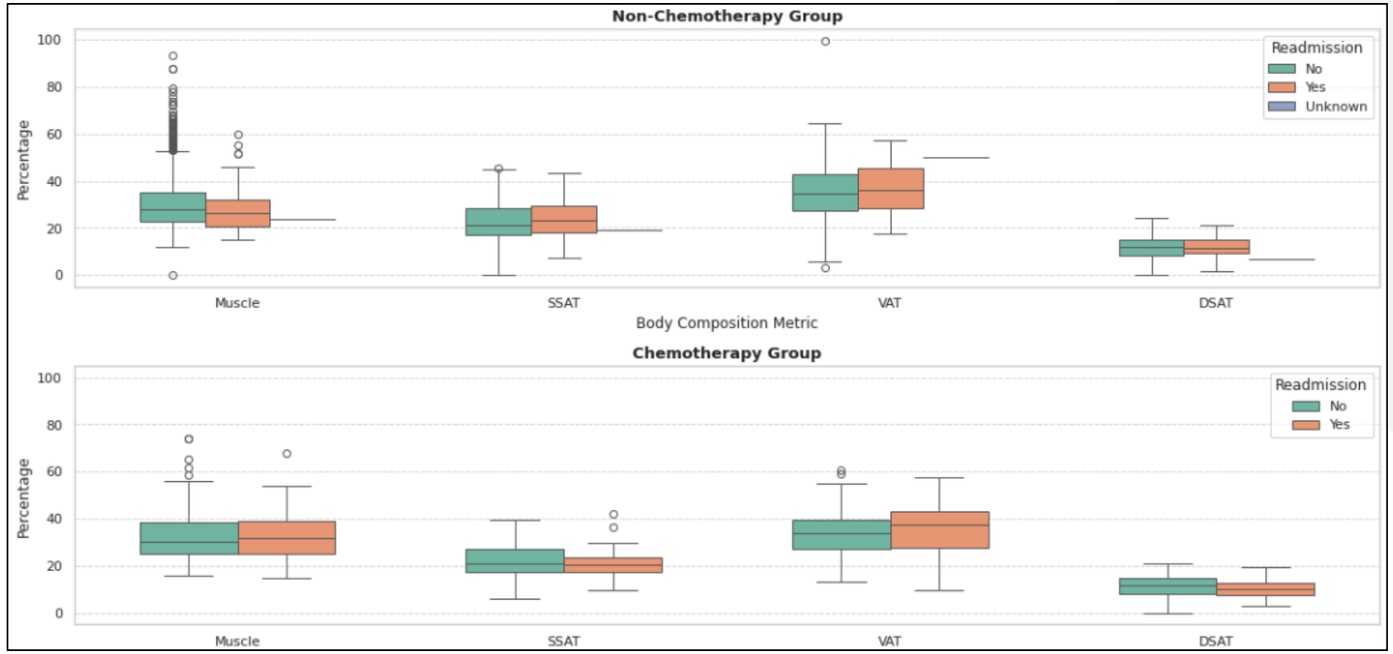
Muscle and SSAT percentages are less discriminatory for predicting readmission in the chemotherapy cohort, indicating potential differences in the underlying mechanisms.

Biomarker Insight: VAT % may be a strong readmission predictor in general surgical patients.

COMPLICATIONS



READMISSION



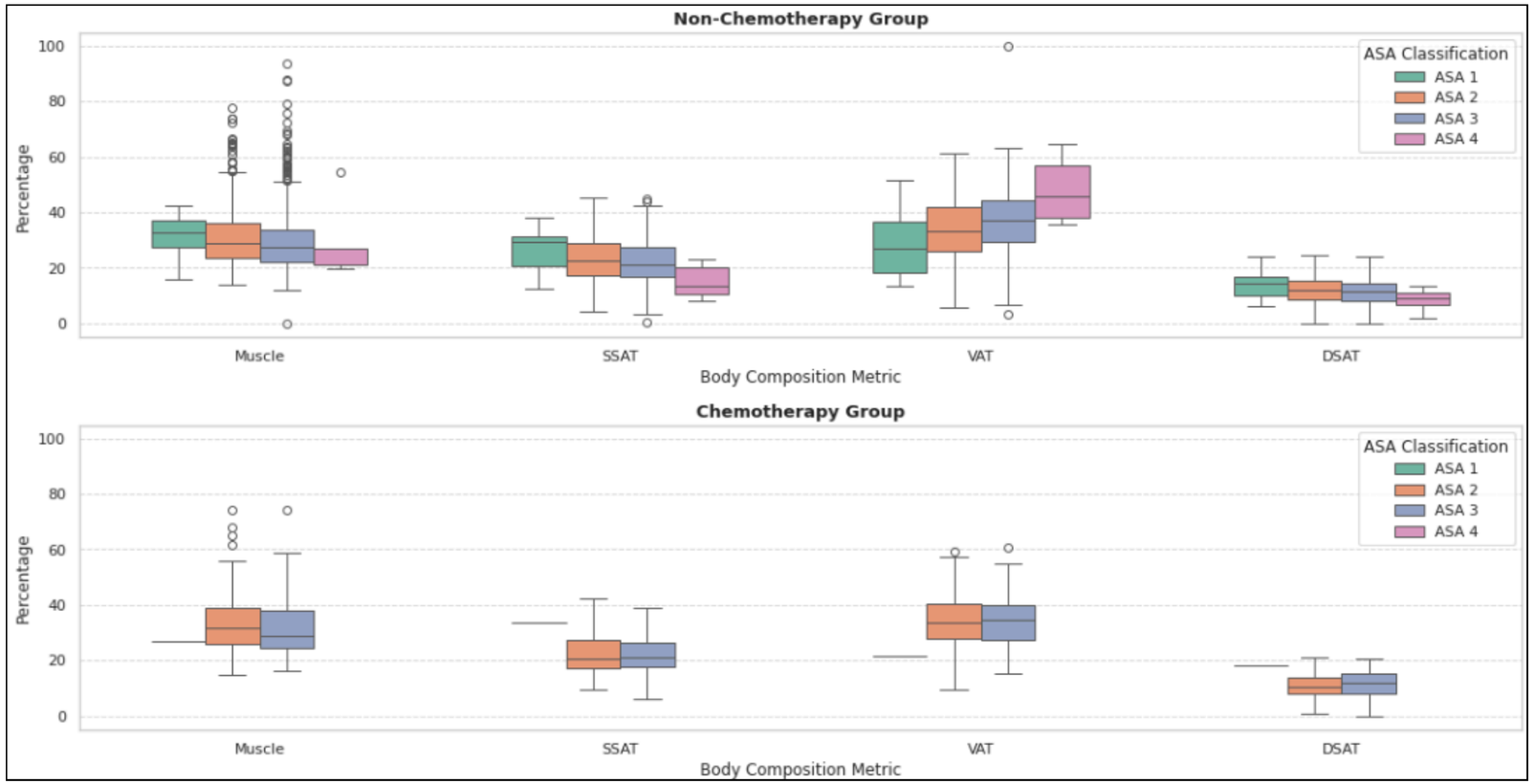
In both chemo and non-chemo groups, patients with complications tend to show:

- Lower Muscle %, indicating possible frailty or poor nutritional reserve.
- Higher VAT %, suggesting a link between visceral adiposity and complication risk.

Readmitted patients in both groups show:

- Slightly lower Muscle % and higher SSAT & VAT %, potentially reflecting incomplete recovery or underlying metabolic risk.
- DSAT % remains low and similar, indicating it may not strongly influence readmission.

Biomarker Insight: Lower muscle mass and higher visceral fat percentages are associated with increased complications and readmission risk, highlighting their potential as predictive biomarkers for postoperative outcomes.



Body Composition Trends Across ASA Classifications

- **ASA I: A healthy patient with no systemic disease.**
- **ASA II: A patient with mild systemic disease that does not limit their activity.**
- **ASA III: A patient with severe systemic disease that limits their activity but is not incapacitating.**
- **ASA IV: A patient with severe systemic disease that is a constant threat to life.**
- **ASA V: A moribund patient who is not expected to survive without surgery.**
- **ASA VI: A declared brain-dead patient whose organs are being removed for donor purposes.**

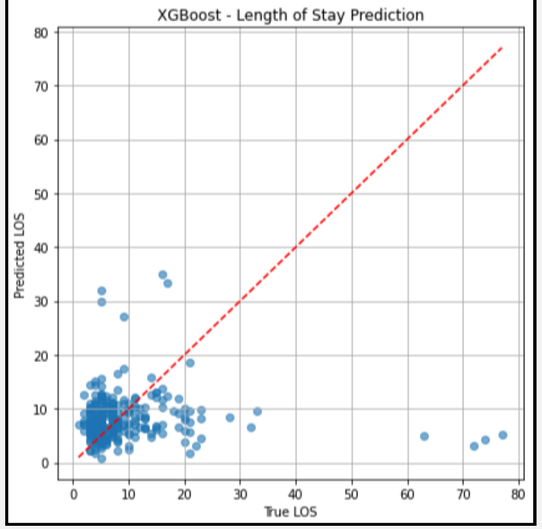
NOTES:

- ASA: A system for categorizing a patient's physical health status before surgery and anesthesia
- Muscle % consistently declines as ASA class worsens in both chemo and non-chemo groups.
- VAT % increases with ASA class, suggesting visceral fat may contribute to systemic disease burden.
- SSAT % shows a mild downward trend, indicating potential nutritional deficits.
- DSAT % declines with higher ASA class, indicating worsening physiological reserve and potential frailty, especially in chemotherapy patients.
- **Biomarker Insight:** Across both chemotherapy and non-chemotherapy groups, higher ASA classifications are associated with lower muscle and subcutaneous fat percentages and higher visceral fat, suggesting that worsening physiological status is reflected in adverse body composition shifts.

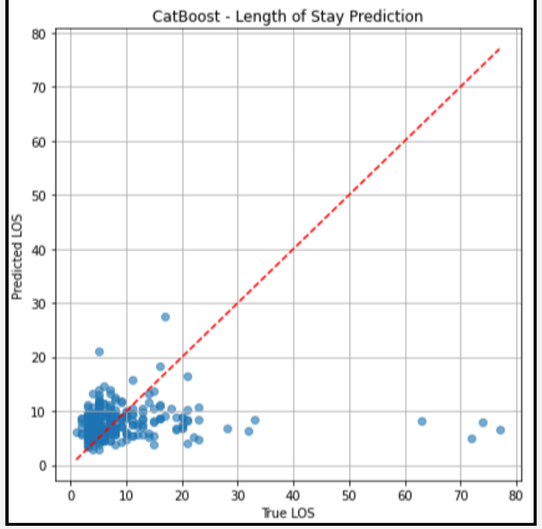
Model Comparison for Length of Stay Prediction

Objective: Evaluate different ML models for predicting patient Length of Stay (LOS).

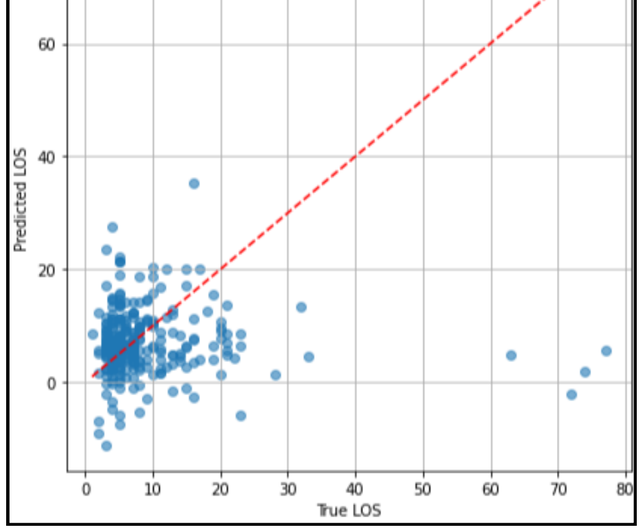
```
==== XGBoost ====
R² Score: -0.223
MSE: 102.897
RMSE: 10.144
Top 5 Features:
  VAT_Muscle_Ratio: 0.1100
  DSATVolcc: 0.0843
  MusclePerc: 0.0837
  VATnumvoxels: 0.0761
  Totalfatcc: 0.0596
```



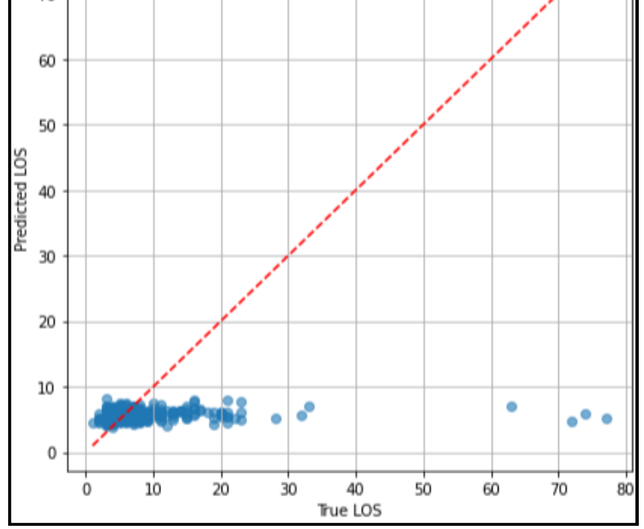

```
==== CatBoost ====
R² Score: -0.063
MSE: 89.377
RMSE: 9.454
Top 5 Features:
  Age: 10.1295
  BMI: 10.0907
  MuscleVolcc: 9.9251
  VATnumvoxels: 6.7514
  Musclenumvoxels: 6.1079
```




```
==== Neural Network ====
R² Score: -0.460
MSE: 122.811
RMSE: 11.082
```




```
==== SVM ====
R² Score: -0.083
MSE: 91.096
RMSE: 9.544
```



Best Performers:
XGBoost (R^2 = 0.223) and CatBoost (R^2 = 0.203) showed strongest correlation with true LOS.

Weak Performance:
SVM had the lowest R^2 (0.083), indicating poor fit despite low RMSE.

Moderate:
Neural Network showed some predictive capacity but with higher error (R^2 = 0.160).

Conclusion:
Tree-based models outperform others in predicting LOS for this dataset. Further tuning or feature engineering may improve performance.

THANK YOU