Assessing Vertebral Metabolism in Lumbar Degenerative Scoliosis Through Deep Learning and FDG PET Imaging

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INTRODUCTION: Degenerative scoliosis is characterized by a lateral curvature of the spine that emerges with age due to degeneration of spinal structures. This condition is especially prevalent in older adults, affecting approximately one in three individuals over the age of 60[1]. Patients with degenerative scoliosis have worse physical health, mental health, and function scores as well as increased pain when compared to other candidates for spinal fusion[2]. While structural changes in degenerative scoliosis are well-characterized through imaging methods like CT and MRI[3], the upstream drivers of degenerative spinal curvature are not well described. Our global hypothesis is that measuring metabolic changes in the spine can identify abnormal spinal growth patterns. Positron emission tomography (PET) using 18 Fluorine – Fluorodeoxyglucose (18F-FDG) is one method to measure glucose metabolism in vivo in humans, and there is evidence of altered 18F-FDG uptake in the lumbar vertebrae with age[4], with degenerative disc/facet joint disease[4,5], and with disc/vertebrae infection[6]. This study aims to investigate FDG PET characteristics in the lumbar vertebrae of degenerative scoliosis patients in the Rush electronic health record (EHR). We hypothesized that spinal level and scoliosis severity are correlated to glucose metabolism.

METHODS: Data for this study (IRB approved) were retrieved from the Rush EHR by querying patients with degenerative lumbar or thoracic scoliosis (ICD10 code: M41.50-57, M41.80-87, M41.90) who underwent PET/CT scans (CPT code: 78812, 78813, 78815, 78816; CT: kVP=120kV, current=294 mA; PET: make=Phillips, injection dose=217-551MBq, time from injection=1 hour) due to suspected tumors, covering the period from 02/2014 to 02/2024. The search identified 40 patients (age: 72±11 years; 40% male, 60% female; BMI: 26.4±6.2). The pipeline implemented in this study includes three steps: ***1) Segmentation of Vertebrae***: Vertebrae from T12 to S1 were segmented using TotalSegmentator[7], a validated deep learning model capable of segmenting major anatomical structures on CT images. ***2) Registration of PET to CT Scans:*** PET scans were registered to CT scans, which served as reference images. PET data were resampled onto the CT grid using cubic interpolation, ensuring consistent resolution and spatial alignment between both scan types. ***3) Calculation of Standardized Uptake Value (SUV):*** Standardized Uptake Value (SUV), a measure of radiotracer uptake normalized to patient body weight and injected dose, was calculated for each segmented PET scan to assess metabolic activity within the vertebrae (**Figure 1a**). Then, we examined the relationship between SUV and spinal level, as well as between SUV and vertebral inclination angle in the coronal plane (**Figure 1b**). This angle was defined as the angle between a vertical line passing through the vertebral centroid and a line perpendicular to the superior endplate of the vertebra on the middle slice in the frontal plane. We determined the maximum coronal inclination angle for each patient as a proxy for scoliosis severity. Finally, we used a linear mixed-effects model to determine the impact of individual (random), spinal level (fixed), and coronal inclination angle (fixed) on SUV, controlling for age, sex, and BMI (**Table 1**).

RESULTS: We observed a decrease in SUV with spinal level, as demonstrated by the graph in **Figure 2** and confirmed by the linear mixed-effects model output in **Table 1**. No statistically significant differences were found in SUV based on the vertebral inclination angle in the coronal plane (**Table 1**). While sex showed no effect, we identified significant differences in SUV related to BMI and age (**Table 1**).

DISCUSSION: This framework advances previous studies by expanding the correlation analysis between SUV and spinal level from a 2D to a comprehensive 3D perspective[8]. It further confirms the trend of decreasing SUV values in lower vertebral levels, likely due to variations in bone marrow composition, as higher SUV observed in PET scans can be attributed to the increased metabolic activity of red bone marrow[8]. Next steps will involve a comprehensive analysis of the correlation between SUV and degenerative scoliosis, with a focus on determining how vertebral location in relationship to scoliotic curvature (concave vs. convex) is related to metabolism.

SIGNIFICANCE: Building on previous findings[8] that establish a correlation between SUV and red bone marrow, the current study reinforces the potential of SUV as an indirect marker of bone marrow composition. Identifying a correlation between SUV and degenerative scoliosis could provide a non-invasive marker for assessing disease severity, as well as offer insights into predicting disease progression and response to treatment.

REFERENCES: [1]McAvoney, *European Spine Journal*, 2020; [2]Rao, *Neurosurgery*, 2015; [3]Kotwal, *HSS Journal*, 2011; [4]Aliyev, *J Nuc Med,* 2012; [5]Rosen, *J Nucl Med,* 2006; [6]Kouijzer, *Eur J Nucl Med Mol Imaging,* 2018; [7]Wasserthal, *Radiology: Artificial Intelligence*, 2023 [8]Shen, *Acta Radiologica*, 2018.

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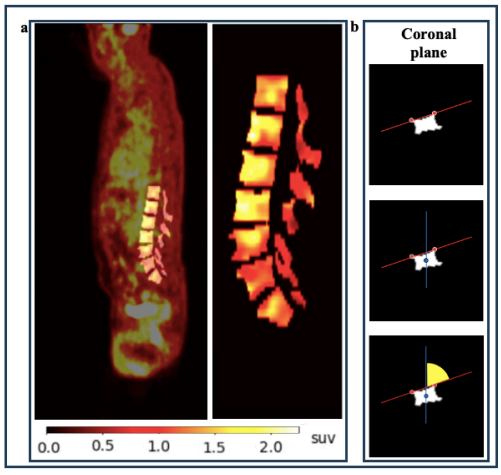

Figure 1: (a) SUV maps of vertebrae from T12 to S1. **(b)** Steps followed to obtain the vertebral inclination angle (central coronal slice)

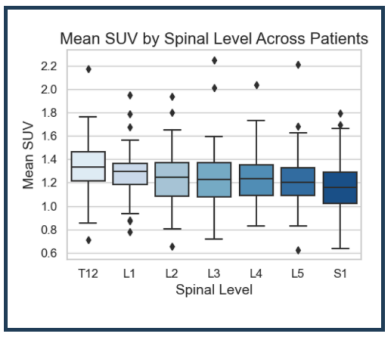

Figure 2: Correlation between spinal level and SUV

Table 1: Results of the linear mixed-effects model estimating the effect of spinal level, vertebral inclination angle, age, sex, and BMI on the outcome variable

Variable	Coefficient	Std Error	p-value
Intercept	1.375	0.252	<0.001
Spinal level: T12 as reference			
L1	-0.054	0.029	0.064
L2	-0.081	0.029	**0.005**
L3	-0.080	0.029	**0.006**
L4	-0.080	0.029	**0.006**
L5	-0.113	0.029	**<0.001**
S1	-0.161	0.029	**<0.001**
Vertebral inclination angle	-0.002	0.002	0.210
Sex: Female as reference			
Male	-0.103	0.071	0.145
Age	-0.006	0.003	**0.044**
BMI	0.016	0.006	**0.008**