Statistical Analysis of Shape and Stress in the Lower Lumbar Spine using Principal Component Analysis and Partial Least Squares Regression

†S. Yeung[1], A. Singh Toor[2], G. Deib[3], J. Zhang[1], T. Besier[1,4], *J. Fernandez[1,4]

[1] Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand.
[2] Auckland City Hospital, Auckland, New Zealand
[3] Mercy Private Hospital, Auckland, New Zealand.
[4] Department of Engineering Science, University of Auckland, Auckland, New Zealand.

*Presenting author: syeu670@aucklanduni.ac.nz
†Corresponding author: j.fernandez@auckland.ac.nz

Abstract

Lower back pain can range from acute tissue inflammation to crippling pain. One potential cause is bone remodelling due to high mechanical stress loadings, which left untreated can lead to severe chronic back problems. Therefore, diagnosis of the type and cause of pain is very important for handling and treatment. This study explores statistical relationships between spinal shapes, Fluorine-18 Sodium Fluoride (^{18}F-NaF) imaging biomarkers [Draper et al. (2012)] and von Mises (VM) bone stress in the lower spine. The biomarkers when used in scans indicate the location of bone remodelling, while the VM stress is dependent on patient parameters such as height and weight. The objectives are to find (i) statistical relationships between shape and NaF/bone stress and (ii) correlating characteristic of shape that influence NaF uptake and bone stress, which provides supporting evidence and further understanding into lower back pain.

Twenty-three orthopaedic data sets of the lower vertebrae from both computed tomography (CT) and ^{18}F-NaF Positron Emission Tomography (PET) were used for the population study. The data had ethical approval obtained by Mercy Hospital, and all 23 patients presented with lower back pain. Techniques used to extract data were: (i) 'Host-mesh' fitting [Fernandez et al. (2004)], used to convert a generic L3, L4, L5, sacrum and coccygeal from the visible human to patient specific geometries for consistent population data; (ii) ^{18}F-NaF registration and mapping, where the NaF hotspots are extracted from the PET scans and aligned and mapped to their corresponding CT geometry models; (iii) principal component analysis (PCA), used to extract the modes of variation for spinal shape, VM stress, and NaF uptake within a population; and (iv) partial least squares regression (PLSR) [Wold et al. (1984)], to find correlations between spinal shape, NaF uptake, and VM stress.

From the total population, 12 patients were classified as 'NaF uptake patients' and 11 patients classified as 'controls'. There were no significant age or BMI differences between males (age 46±19 years; BMI 27±5) and females (age 43±17 years; BMI 27±7). From the population, PCA revealed that spinal shape could be represented by 3 key features (i) sacral tilt, (ii) spinal curvature, and (iii) intervertebral disc spacing. PLSR linked these spinal shape features to determine: NaF was most influenced by sacral tilt, spinal curvature, and vertebral disc spacing, respectively; bone stress was most influenced by sacral tilt, vertebral disc spacing, and medial-lateral tilt, respectively. Fig. 1 shows the ability of the PLSR model in predicting a linear correlation between NaF uptake and spinal geometry for a representative 'NaF uptake patient' from the population data set. PLSR also found correlations between the regions of peak NaF uptake and peak VM stress.

Analysis of the PCA and PLSR models, show that: (i) linear correlations exist between shape and NaF uptake/bone stress and (ii) both are mainly affected by sacral tilt. This indicates that a person's spinal shape affects their VM bone stress, which in turn causes higher NaF uptake due to bone remodeling. This suggests that spinal shape may play a predictor role in clinics for patient bone stress and NaF identification.

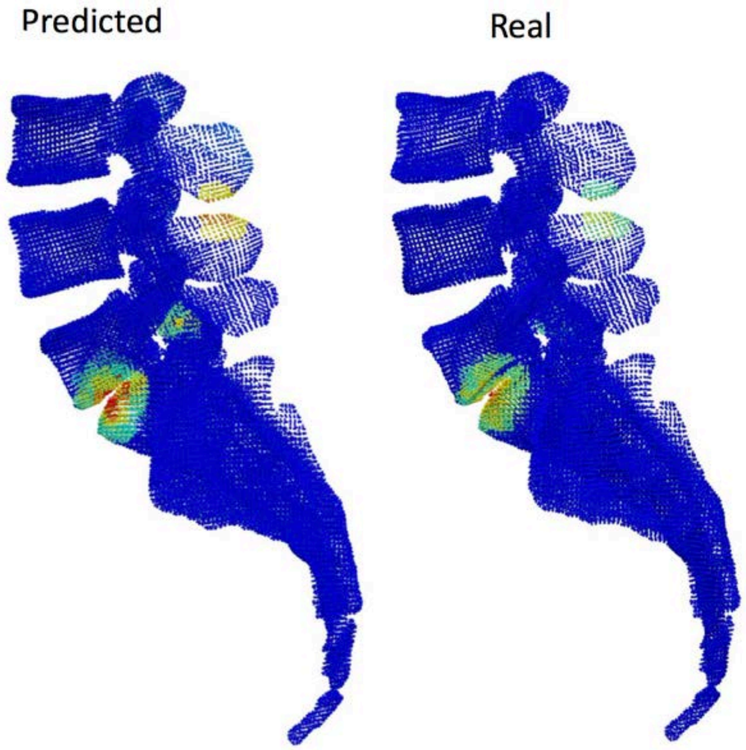

Figure 1 - The PLSR predicted NaF uptake model (right) compared to the original NaF uptake (left) from PET scans, both being displayed on the host meshed patient geometry (navy blue spheres). The patches of color range from red (high/peak NaF uptake) to aqua (small amount of NaF uptake), where no NaF is indicated with navy blue.

Keywords: Principal Components, Partial Least Squares, lower lumbar stress, back pain, shape analysis, ^{18}F-NaF uptake

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