

WHAT IS CLAIMED IS:

1. A three-dimensional medical image analysis system for predicting a presence of a vertebral fracture in a subject, comprising:

a 3D image processor for receiving and processing 3D image data of a 3D image of the subject, producing two or more sets of 3D voxels including a first set of 3D voxels and a second set of 3D voxels, each of the first set of 3D voxels and the second set of 3D voxels corresponding to an entirety of the 3D image, 3D voxels of the first set of 3D voxels each being of equal dimensions, 3D voxels of the second set of 3D voxels each being of equal dimensions, the 3D voxels of the first set of 3D voxels being of different dimensions than the 3D voxels of the second set of 3D voxels;

a voxel classifier for assigning the 3D voxels of the first set of 3D voxels and the 3D voxels of the second set of 3D voxels one or more class probabilities each of the 3D voxels contains a fracture using a computational model; and

a fracture probability estimator for estimating a probability of the presence of a vertebral fracture in the subject based on the one or more class probabilities of each the 3D voxels of the first set of 3D voxels and each of the 3D voxels of the second set of 3D voxels.

2. The system of claim 1 further comprising a spinal cord detector for detection of a part of the 3D image comprising the spinal cord.

3. The system of claim 2, wherein the spinal cord detector uses maximum signal intensities to locate the spinal cord in said the 3D image data.

4. The system of claim 3, wherein the spinal cord detector uses anatomical prior information to locate the spinal cord along the x, y and z axes.

5. The system of claim 1, wherein at least one of the sets of 3D voxels is a set of isotropic voxels of 1 mm^3 .

6. The system of claim 1, wherein the first set of 3D voxels is a set of isotropic voxels of 1 mm³, and the second set of 3D voxels is a set of isotropic voxels of 3 mm³.
7. The system of claim 6, wherein the voxel classifier is configured to classify each of the 3D voxels in the context of the surrounding 3D voxels, and classifies each of the 3D voxels in the first set in the context of 30-40 mm³ of the 3D voxels and each of the 3D voxels in the second set in the context of 90-120 mm³ of the 3D voxels.
8. The system of claim 7, the first set of 3D voxels is classified in the context of 35 mm³ of the 3D voxels and the second set of 3D voxels is classified in the context of 105 mm³ of the 3D voxels.
9. The system of claim 1, wherein at least one of the sets of 3D voxels is a set of anisotropic voxels.
10. The system of claim 1, wherein the 3D image processor is configured to output a set of 3D voxels that are normalized to mean and unit standard deviation of the intensity of the set of 3D voxels.
11. The system of claim 1, wherein the voxel classifier classifies each of the 3D voxels in the one or more of the sets of 3D voxels in the context of the surrounding 3D voxels.
12. The system of claim 11, wherein the voxel classifier is utilizing a CNN comprising a set of neural network layers, wherein the sequence of neural network layers comprises:

for each set of 3D voxels, one or more convolutional layers configured to receive an input derived from the set of 3D voxels in the context of the surrounding 3D voxels to generate two or more convolved outputs;

one or more fully connected layers configured for aggregating the two or more convolved outputs; and

a classification layer configured for receiving an input from the one or more fully connected layers to perform a final classification.

13. The system of claim 12, wherein the final classification is assigning a probability to each of the 3D voxels to be classified as normal, fracture or background.
14. The system of claim 1, wherein the voxel classifier is configured to classify each 3D voxel using a pre-trained classifier by assigning one or more class labels to the 3D voxel.
15. The system of claim 1, wherein the voxel classifier is configured to calculate for each 3D voxel a probability to be classified as background, normal, fracture class.
16. The system of claim 1, wherein the fracture probability estimator comprises an image classifier that is configured to classify the 3D image into having or not having a fracture and receives an input from the voxel classifier for each 3D voxel of the 3D image and provides an output of an aggregated probability value for the 3D image.
17. The system of claim 16, wherein the image classifier is configured to classify the 3D image based on a minimum threshold value of a number of 3D voxels having an assigned probability of a fracture class.
18. The system of claim 1, wherein the fracture probability estimator comprises a vertebra anatomical label assignor to assign anatomical level information to each vertebrae present in the 3D image.
19. The system of claim 1, wherein the voxel classifier is pre-trained using a set of annotated input 3D images divided into 3D voxels, wherein an intensity noise signal is added to each 3D voxel along x, y and z axes.
20. The system of claim 1, wherein the voxel classifier utilizes a CNN pre-trained using a set of annotated input 3D images using a sampling ratio to favor foreground.
21. The system of claim 1, wherein the voxel classifier utilizes a CNN pre-trained using a set of annotated input 3D images using a sampling ratio of background:normal:fracture of 1:3:3.
22. A medical imaging workstation comprising:

an imaging apparatus for generating at least one 3D image of a subject; and

the system as recited in claim 1 for predicting the presence of a vertebral fracture in the subject in at least one generated image.

23. The system of claim 1, wherein the voxel classifier includes at least one first convolutional layer for analyzing the 3D voxels of the first set of 3D voxels and at least one second convolutional layer for analyzing the 3D voxels of the second set of 3D voxels, the voxel classifier further including one or more connected layers configured to aggregate outputs produced from the at least one first convolutional layer for the 3D voxels of the first set of 3D voxels and outputs produced from the at least one second convolutional layer for the 3D voxels of the second set of 3D voxels.

24. A three-dimensional medical image analysis method of predicting the presence of a vertebral fracture in an individual, the method comprising the steps of:

receiving a 3D imaging data of a 3D image comprising 3D imaging information of the spinal cord;

processing the 3D image and producing two or more sets of 3D voxels including a first set of 3D voxels and a second set of 3D voxels, wherein each of the first set of 3D voxels and the second set of 3D voxels corresponds to the entirety of the 3D image, and wherein 3D voxels of the first set of 3D voxels each being of equal dimensions, 3D voxels of the second set of 3D voxels each being of equal dimensions, the 3D voxels of the first set of 3D voxels being of different dimensions than the 3D voxels of the second set of 3D voxels;

computing for each 3D voxel of the first set of 3D voxels and the 3D voxels of the second set of 3D voxels a class probability of each 3D voxel to contain a fracture using a computational model;

identifying if any of the 3D voxels of the first set of 3D voxels and the 3D voxels of the second set of 3D voxels are classified as containing a fracture; and

predicting the presence of a vertebral fracture in the individual based on the identification of the 3D voxels of the first set of 3D voxels and the 3D voxels of the second set of 3D voxels classified as containing a fracture.

25. The method of claim 24 further comprising a step of locating within the 3D image the spinal cord and generating spine-cropped output images for each set of 3D voxels including the spinal cord and outputting sets of 3D voxels including the spinal cord.

26. The method of claim 25, wherein the step of locating within the image the spinal cord uses anatomical prior information to coarsely locate the spinal cord along the x, y and z axes.

27. The method of claim 24, wherein the classification of 3D voxels as containing a fracture is performed using a model trained using a training data set generated using a method comprising following steps:

- i. inputting via a user interface centroid coordinates for each vertebra in a training image;
- ii. inputting via the user interface a vertebra fracture label;
- iii. fitting a Gaussian centroid likelihood function around selected centroid coordinates;
- iv. producing a dataset of pairs of signal intensity and label for each of the training images in the training data set.

28. The method of claim 24, wherein the processing of the 3D image and producing two or more sets of 3D voxels includes adding an intensity noise signal to each produced 3D voxel along x, y and z axis.

29. The method of claim 24, wherein at least one of the sets of 3D voxels is a set of isotropic voxels.

30. The method of claim 24, wherein the step of computing for each 3D voxel the class probability of the 3D voxel to contain fracture using the computational model includes

classification each of said the 3D voxels in the one or more sets of 3D voxels in the context of the surrounding 3D voxels.

31. The method of claim 30, wherein the classification of each of the 3D voxels is performed in the context of the surrounding 3D voxels, and classifies each of the 3D voxels in the first set 3D voxels in the context of 30-40 mm³ of the 3D voxels and each of the 3D voxels in the second set of 3D voxels in the context of 90-120 mm³ of said the 3D voxels.

32. The method of claim 24, wherein the step of computing for each 3D voxel class the probability of the 3D voxel to contain a fracture using the computational model produces an output probability to be classified as a background, normal, or fracture class for each 3D voxel in the 3D image.

33. The method of claim 24, wherein the step of predicting the risk of a vertebral fracture includes classification of the 3D image into having or not having a fracture, and wherein the step of predicting the risk of a vertebral fracture includes receiving an input classification value computed by the step of computing for each 3D voxel class probability of the 3D voxel to contain fracture using the computational model for each 3D voxel of the 3D image, and wherein the step of predicting the risk of a vertebral fracture provides an output of an aggregated probability value for the 3D image.

34. The method of claim 24, wherein the step of predicting the risk of a vertebral fracture includes classification of the 3D image based on a minimum threshold value of a number of 3D voxels having an assigned probability of a fracture class.

35. The method of claim 24 further comprising a step of vertebra classification by assigning a probability of the vertebrae having a fracture.

36. The method of claim 24, wherein the step of computing for each 3D voxel the class probability of the 3D voxel to contain a fracture using the computational model utilizes a Convolutional Neural Network (CNN) comprising a set of neural network layers, wherein the set of neural network layers comprises:

for each set of 3D voxels, one or more convolutional layers configured to receive an input derived from the set of 3D voxels in the context of the surrounding 3D voxels to generate two or more convolved outputs;

an aggregation layer for aggregating an output from the one or more convolved outputs for each of the sets of 3D voxels;

one or more convolutional layers receiving an input from the aggregated output from the one or more convolved outputs;

one or more fully connected layers for aggregating the two or more convolved outputs; and

a classification layer receiving an input from the one or more fully connected layers to perform a final classification.

37. The method of claim 36, wherein the final classification is performed by assigning a probability to each of the 3D voxels to be classified as normal, a fracture or background.

38. A computer program product, disposed on a non-transitory computer readable media, comprising computer executable code for performing the steps of the method of claim 24 on a computer.

39. A three-dimensional medical image analysis method of predicting the presence of a vertebral fracture in an individual, the method comprising the steps of:

receiving a 3D imaging data of a 3D image comprising 3D imaging information of the spinal cord;

processing the 3D image and producing two or more sets of 3D voxels, wherein each of the sets of 3D voxels corresponds to the entire the 3D image, and wherein each of the sets of 3D voxels consists of equal 3D voxels of different dimensions;

computing for each 3D voxel a class probability of each 3D voxel to contain a fracture using a computational model;

identifying if any of the 3D voxels are classified as containing a fracture; and

predicting the presence of a vertebral fracture in the individual based on the identification of the 3D voxels classified as containing a fracture, wherein the classification of 3D voxels as containing a fracture is performed using a model trained using a training data set generated using a method comprising following steps:

- i. inputting via a user interface centroid coordinates for each vertebra in a training image;
- ii. inputting via the user interface a vertebra fracture label;
- iii. fitting a Gaussian centroid likelihood function around selected centroid coordinates;
- iv. producing a dataset of pairs of signal intensity and label for each of the training images in the training data set.