Early detection of osteoporosis using handgrip test results with a machine learning model

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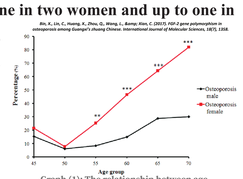
Abstract

Osteoporosis is a bone disease that reduces the density of the bones to the point where they fracture easily. The aim of the study is the early detection of osteoporosis before causing any fractures to the bones, which is achieved by using a potential indicator that divides into two main steps. First, the Hand Grip Strength (HGS) test measures bone strength. Second, a dataset is integrated, utilizing different variables, including the HGS test results. The purpose is to determine the T-score which is the bone density of the body compared to the normally expected result. This dataset is used in creating a machine-learning model which indicates osteoporosis in the patient's bones. After indicating the expected T-score, the created software directs osteoporosis patients to the next step in the therapeutic process. The result of the search and study revealed a statistically significant correlation between the handgrip test data and T-score. This potential therapeutic indicator shows a high correlation between T-score values and handgrip strength, leading us to a new potential parameter in the development of predictive models that could be used in clinical practice, highlighting its importance for the diagnosis of osteoporosis.

Research Background

osteoporosis is a bone disease that causes bones to be more brittle and susceptible to fracture. The percentage of osteoporosis is very high among old people, according to the bone health and osteoporosis organization, one in two women and up to one in four men over age 50 will break a bone due to osteoporosis, and this number increases proportionally with age as shown in graph (1). The main problem of Osteoporosis is its fractures since the disease is responsible for an estimated two million broken bones per year, and osteoporosis fractures are not easy, impossible in some cases, to heal, unlike the main disease.



Graph (1): The relationship between age and percentage of osteoporosis percentage

Osteoporosis patients can't know about their disease until the first fracture, so the aim of the study is early detection of osteoporosis using a computer-based indicator that uses previous experiments to create a relation between various variables such as gender, weight, age, Handgrip Strength test, body mass index, and T-score, which represents the bone density, to get the opportunity to be infected with osteoporosis, and to prevent any osteoporosis-fracture injuries.

In order to achieve the project's goal, the sensitivity and specificity of the indicator will be measured. First, the project should achieve three main requirements. The model should be easy to use, low in cost, and fast in processing data. Then, the main criterion of the project is to achieve an accuracy higher than 80%. In addition, the total of the sensitivity and the specificity is intended to be greater than 1. To achieve these design requirements, we used many materials in the project.

Materials

Name	Description	Figure
Python 3	Python 3 is a high-level programming language used as a general-purpose programming language used in many fields and specialized in data analysis, machine learning, and data visualization.	
Google Collaboratory	Google Colab is a Google Research product that is used for Python programming language and specialized in machine learning and data analysis.	
Hang grip dynamometer	A device that is used to determine the strength and health of your body and used to calculate the strength of muscles, bones, and nerves.	
SAS	SAS (Statistical Analysis System) is a statistical software developed by SAS Institute which is used for data management and advanced analytics.	

Table (1): The table shows the materials used in the project

Procedures

1- First, reviewing many research papers about osteoporosis, some correlations have been found between the physical parameters of the body and bone mineral density.

2- The main parameters used for the dataset are the Handgrip strength test, body mass index (BMI), body weight, body height, age, gender, and race.

3- After that, searching for many datasets to find the best that contains the specified parameters, we found a general health survey program made by the Center of Disease Control and Prevention (CDC) named "The National Health and Nutrition Examination Survey (NHANES)."

4- The needed data were downloaded from each category from NHANES 2013-2014 and 2011-2012 as it has all the needed parameters. First, the data was downloaded in the XPT format, so we used the SAS program to open the data and select the needed columns. As shown in figure (1).

5- The data then was converted to CSV format and uploaded to Google Drive to be used in Google Colab. A python notebook was used for the project. The datasets were uploaded to pandas DataFrames and merged into one dataset.

6- The uncompleted data because of the merging was dropped from the dataset, ending with 5343 training samples.

7- Using the Bone Mineral Density (BMI), we made a new column that is true if the person has the disease and false if he is healthy.

8- To choose the features used to train the model, we split the data into categorical data for which we used P-value, and numerical data for which we used ANOVA F-value, as shown in figure (2). The data was reduced to 13 columns of which two are categorical and the rest are numerical.

9- the data was divided into X features and the y value which will be predicted. The predicted value was chosen to be Bone Mineral Density (BMD). The X and y data, then, was split into training (80%) and test (20%) datasets.

10- For the prediction, we used a Neural Network (figure 3) consisting of three hidden layers two of them have 10 neurons, and one with 5 neurons with ReLU activation function. In addition, the output layer consists of one neuron with a sigmoid activation function.

11- Then, the confusion matrix was calculated to evaluate the performance of the deep learning model and calculate the sensitivity, specificity, and accuracy of the model.

Columns used in for the dataset

```
[1]  columns = ['SEQN', 'BMXWT', 'BMXHT', 'BMXBMI', 'BPQ020', 'BPQ080', 'PEASCST1',\
                'PEASCTM1', 'RIAGENDR', 'RIDAGEYR', 'RIDRETH3', 'DIQ010', 'KIQ022',\
                'KIQ026', 'MGQ070', 'MGQ100', 'MGXH1T1', 'MGXH1T1E', 'MGXH2T1',\
                'MGXH2T1E', 'MGXH1T2', 'MGXH1T2E', 'MGXH2T2', 'MGXH2T2E', 'MGXH1T3',\
                'MGXH1T3E', 'MGXH2T3', 'MGXH2T3E', 'MGDCGSZ', 'DXXLABMC', 'DXXLABMD',\
                'DXXRABMC', 'DXXRABMD', 'DXDTOBMC', 'DXDTOBMD']
```

Figure (1): Different coloums used from the dataset

Choosing categorical features using P-value

```
[ ]  statistic, p_val = chi2(x_train[categorical_cols], y_train)
     selected = (pd.Series(p_val,index = categorical_cols) < 0.05)
     categorical_cols_selected = selected[selected].keys().to_list()
     categorical_cols_selected
```

Choosing numerical data using ANOVA F-value

```
[ ]  fs = SelectKBest(score_func=f_classif, k='all')

     fs.fit(x_train[numiric_cols], y_train)

     x_train_fs = fs.transform(x_train[numiric_cols])
     x_train_fs = pd.DataFrame(x_train_fs, index=x_train.index, columns=x_train[numiric_cols].columns)

     x_test_fs = fs.transform(x_test[numiric_cols])
     x_test_fs = pd.DataFrame(x_test_fs, index=x_test.index, columns=x_test[numiric_cols].columns)

[ ]  x_train_selected = pd.concat([x_train_fs, x_train[categorical_cols_selected]], axis=1)
     x_test_selected = pd.concat([x_test_fs, x_test[categorical_cols_selected]], axis=1)
```

Figure (2): Choosing numerical data using ANOVA F-value

Neural Network Layers

```
[ ]  model = Sequential()
     model.add(Dense(10, input_dim=x_train_selected.shape[1], activation='relu'))
     model.add(Dense(10, activation='relu'))
     model.add(Dense(5, activation='relu'))
     model.add(Dense(1, activation='sigmoid'))
```

Fitting the training data

```
[ ]  model.compile(loss='binary_crossentropy', optimizer='adam', metrics=['accuracy'])

     history = model.fit(x_train_selected, y_train.to_numpy(), validation_split=0.3, epochs=100, batch_size=32)
```

Predicting test data

```
[ ]  y_pred = model.predict(x_test_selected) > 0.6
```

Figure (3): Using 3 hidden layers for the prediction

Results

Negative result:

After testing the first version of the model, we got a negative result which was the low sensitivity, which was approximately 33%, we have fixed this problem by using a deep learning model instead of a linear regression model, which was used as a main predicting method.

Positive result:

After testing the new deep learning model, an actual vs predicted values graph and a table of confusion have been made as shown in figure (4). The accuracy and summation of sensitivity have been calculated and the results were:

Accuracy = 80.45% , Sensitivity = 80.47% , Specificity = 80.42% , The summation of sensitivity and specificity = 1.61 which achieves our design requirements.

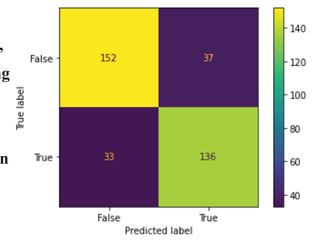


Figure (4): Table of confusion

Analysis

Osteoporosis:

Osteoporosis is a disease that weakens the bone and makes them break more easily as shown in figure (5). Osteoporosis develops slowly through the years and most of the time only diagnosed when bone starts breaking which is called fractures. Osteoporosis can be treated easily, unlike its fractures, by using bone-strengthening medicines. The main cause of osteoporosis is an error in the ratio between osteoclast, responsible for bone resorption, and osteoblast, which build new lamellae cells shown in figure (6), which is normally 1 osteoclast: 2 osteoblasts.

The stage before osteoporosis is called osteopenia. This is when a bone scan shows a lowering in bone density. There are specific hormones in the body which affect bone density causing osteoporosis such as sex hormones, estrogen in females, and testosterone in males, in addition to calcium regulating hormones which are mainly parathyroid hormone (PTH), produced by the thyroid glands helps maintain the right balance of calcium in the bloodstream, calcitonin, that increase calcium level in the bloodstream, and calcitriol, that lower calcium level in the bloodstream.

MediLexicon International. (n.d.). Vitamin D levels may predict future health risks, death in older men. Medical News Today. Retrieved January 28, 2023,

Figure (5): Osteoporosis through years

Osteoporosis | osmosis. (n.d.). Retrieved January 27, 2023,

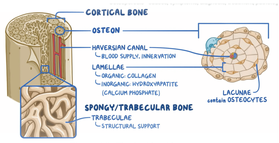


Figure (6): The inside of bones

T-score:

T-score represents the bone density of a body compared to a healthy body with the same gender and age. The T-score is the number of units, standard deviation, that the density of the bone is above or below the average. There are three cases based on T-score shown in figure (7).

The healthy case is when T-score is above -1. The interval between -1 and -2.5 is where bones are diagnosed with osteopenia. The last case is with a T-score below -2.5, this means that the body's bones have osteoporosis.

Providencecadmin. (2021, August 31). What is T score?: T score bone density: providence. Retrieved January 28, 2023,

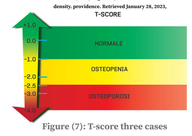


Figure (7): T-score three cases

Handgrip strength test:

The handgrip Strength test (HGS test) is an easy test used to determine a person's general body strength. The tools used in this test are called handgrip dynamometers. After many studies and data collection, between 2015 to 2020 from a total of 6504 patients, a statistically significant correlation between T-score and handgrip strength has been revealed ($p < 0.001$). the variables that have been tested were age, vitamin D, handgrip, and T-score in different groups of healthy and osteoporotic samples.

Deep learning:

Deep learning is a branch of machine learning which depend on the usage of Neural Networks to simulate human brain behavior making it able to learn from a large amount of data to make classification predictions. The deep neural network (figure 8) is a series of functions consisting of three or more layers where the output of each layer becomes the input of the second one. Layers of neural networks consist of three types of layers the input layer, hidden layers, and the output layer. Each layer consists of neurons with a specific activation function that processes the input to make a prediction. The neural network optimizes the activation functions' parameters through processes of gradient descent and backpropagation.

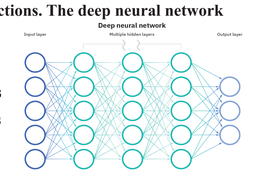


Figure (8): Deep neural network

Jayaweera, P. V. (2021). Design and implementation of electromyography (EMG) based real-time pattern recognition model for Prosthetic Hand Control.

Conclusion

The result of the search and study revealed a statistically significant correlation between the handgrip test data and T-score. This potential therapeutic indicator shows a high correlation between T-score values and handgrip strength, leading us to a new potential parameter in the development of predictive models that could be used in clinical practice, highlighting its importance for the diagnosis of osteoporosis.

Future Applications

In the future, the model will be supported with more data that will increase its accuracy and will help get a more detailed diagnosis of a patient's condition instead of just indicating the disease. The model should be able to determine the cause of the disease whether the reason was a genetic issue, bad lifestyle, or medical condition.

If the reason was medical, the created software should be able to direct osteoporosis patients, more precisely, to the next step in the therapeutic process to help their recovery. And it should give suggestions for a specific food or exercise to strengthen the patient's bones if the reason for the disease was a bad lifestyle.

The model should also be able to diagnose more bone diseases other than osteoporosis such as cervical spondylosis, metatarsalgia, bone cancer, or osteoarthritis to be able to help people as much as possible (figure 9).

Premium vector: Back, bones and human spin diseases explanation vector. Freepik. (2019, October 11). Retrieved January 28, 2023,

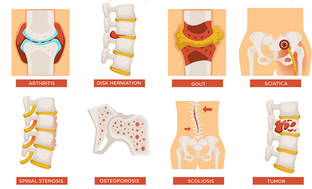


Figure (9): different types of bone diseases

Citation

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3- Lee, S. H., & Gong, H. S. (2020). Measurement and interpretation of Handgrip strength for research on sarcopenia and osteoporosis. Journal of Bone Metabolism, 27(2), 85. https://doi.org/10.11005/jbm.2020.27.2.85

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5- Nordström, P., Nordström, G., & Lorentzon, R. (1997). Correlation of bone density to strength and physical activity in young men with a low or moderate level of physical activity. Calcified Tissue International, 60(4), 332–337. https://doi.org/10.1007/s002239900238