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An Informative Machine-Learning Tool for Diagnosis of Osteoporosis using Routine Femoral Neck Radiographs

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Abstract

Background

One in three women in the world develops osteoporosis, which weakens the bones, causes atraumatic fractures and lowers the quality of life. The damage to the bones can be minimized by early diagnosis of the disease and preventive treatment, including appropriate nutrition, bone-building exercise and medications. Osteoporosis is currently diagnosed primarily by DEXA (Dual Energy X-ray Absorptiometry), which measures the bone mineral density alone. However, bone strength is determined not only by its mineral density but also by the spatial structure of bone trabeculae (See Figure 1). In order

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to obtain valuable information regarding the bone strength, the mineral content and the spatial structure of the bone tissue should be objectively assessed.

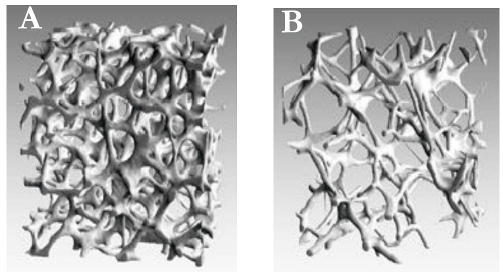


Figure 1. The spatial structure of bone tissue trabecula.
A. A normal bone **B.** An Osteoporotic bone

PURPOSE

The aim of the study was to analyze the structure of the bone tissue by using texture analysis of the bone trabeculae, as visualized in a routine radiograph of the proximal femur (See Figure 2). This could provide objective information regarding both the mineral content and the spatial structure of bone tissue. Therefore, machine-learning tools were applied to explore the use of texture analysis for obtaining information on the bone strength.

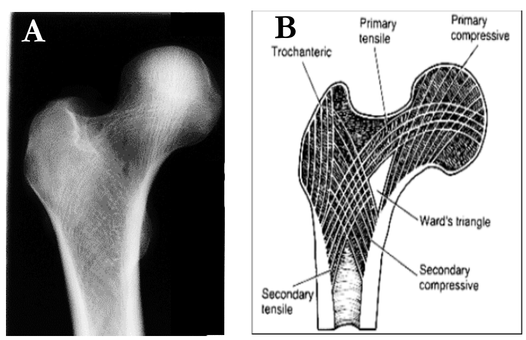


Figure 2. Spatial structure of bone trabecula in the proximal femur.
A. A visual view of the bone trabecula in a routine radiograph of the proximal femur.
B. A schematic view of the pattern of bone trabeculae.

METHODOLOGY

The study includes 17 radiographs of in-vitro femurs without soft tissue and 44 routine proximal femur radiographs (15 subjects with osteoporotic fractures and 29 without a fracture). The critical force required to fracture the in-vitro femurs was measured and the bones were divided into two groups: 11 solid bones with critical fracture force higher than 4.9kN and 6 fragile bones with critical fracture force lower than 4.9kN. All the radiographs included an aluminum step-wedge for calibrating the gray-levels values (See Figure 3). An algorithm was developed to automatically adjust the gray levels in order to yield equal brightness and contrast.

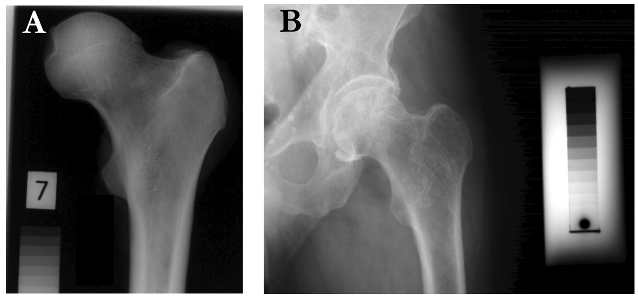


Figure 3. A radiograph of the proximal femur, with an aluminum step-wedge.
A. An in-vitro bone radiograph **B**. A routine radiograph of an in-vivo bone

Then, Texture analysis was performed on two regions of interest (ROI), for each bone. The upper ROI in the femoral neck includes the bone trabeculae in the proximal femur and the lower ROI, located distally to the lesser trochanter, includes also the compact bone (see Figure 4).

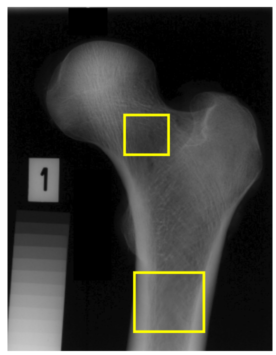


Figure 4. The analyzed ROIs in the radiograph of the proximal femur.

Eleven numerical features were extracted for the texture analysis of each ROI. These features include 6 texture characteristics, based on the global distribution of the gray-level values, such as the mean, the standard deviation, the contrast and the statistical entropy. Five additional features, such as smoothness, uniformity and statistical energy, were based on the spatial allocation of the gray-levels in the ROI. The latter five features were computed using the Gray Level Co-occurrence Matrix (GLCM), which take into account the bivariate distribution for pairs of gray levels appearing side-by-side.

Supervised machine learning was used to classify the bones by their bone strength. The analysis was based on the evaluation of a vector of 22 features, extracted for each bone from both ROIs. Support Vector Machine (SVM) was used to train the algorithm and test its results. Since the number of cases included in the study was relatively small, a cross-validation method was applied to evaluate the classification success rate. The cases were, thus, randomly divided into 5 groups. Training was carried out using 4 groups of the cases, while classification was tested on the fifth group. This process was repeated five times, varying the test group and training groups.

Findings

The algorithm characterized the in-vitro bones with as fragile or solid with an accuracy of 88%. For the radiographs of the patients, the algorithm characterized the bones as osteoporotic or non-osteoporotic with an accuracy of 86%. The most prominent features for estimating the bone strength were the mean gray-level, which is related to bone density, and the smoothness, uniformity and entropy, which are related to the spatial distribution of the bone trabeculae.

IMPACT ON SOCIETY

Analysis of bone tissue structure, using machine-learning tools will provide a significant information on the bone strength, for the early diagnosis of osteoporosis. The structure analysis can be performed on routine radiographs of the proximal femur, with high accuracy.

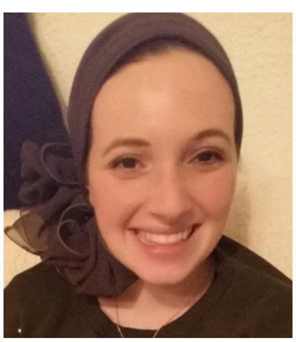
FUTURE RESEARCH

The algorithm for automatic structure analysis of bone tissue as visualized on a routine femoral radiograph should be further trained on a larger dataset of routine radiographs in order to improve the accuracy of assessing the bone strength.

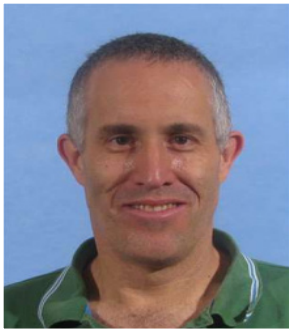
BIOGRAPHIES

Dr. Talia Yeshua holds a Ph.D. in applied physics from the Hebrew University of Jerusalem. Her doctoral dissertation involved an interdisciplinary research in the field of nanoprinting and nanoelectronics. She is a lecturer in the Department of Applied Physics/Electro-Optics Engineering at the Jerusalem College of Technology. Her research focus on computerized diagnosis of various pathologies in medical images, using computer vision and machine learning tools.

Sarah Rebibo completed her undergraduate studies in computer science at the Jerusalem College of Technology. Her research involves development of algorithms for detecting pathologies in medical images using advanced image processing and machine learning tools.



Keren Jacobson completed her undergraduate studies in computer science at the Jerusalem College of Technology. Her research involves development of algorithms for detecting pathologies in medical images using advanced image processing and machine learning tools.



Dr. Ori Safran is the head of shoulder surgery center at Hadassah University Hospital in Jerusalem. He is the former chairman of the Israeli shoulder and elbow society. He is Expert in shoulder trauma and shoulder fracture fixation.

Professor Meir Liebergall is the director of the musculoskeletal division and chairman of the department of orthopedic surgery at Hadassah University Hospital in Jerusalem. He is an expert in orthopedic trauma, pelvic fractures, fracture complications and joint replacement (hip / knee). His research includes computer-assisted surgeries in orthopedic trauma and joint replacement, arthritis and joint replacement and tissue engineering for fracture fusion

Professor Leichter holds a Ph.D. from the Hebrew University of Jerusalem. He specialized in medical physics and medical engineering at UCLA and the Hebrew University. He is a Full Professor in the Department of Applied Physics/Electro-Optics Engineering and head of the Medical Optics Laboratory at the Jerusalem College of Technology.