ARTIFICIAL INTELLIGENCE FOR BONE DISORDER

Diagnosis and Treatment

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Foreword

I am delighted to introduce the book "Artificial Intelligence for Bone Disorder: Diagnosis and Treatment," authored by Dr. Rishabha Malviya. This extensive collection of reports explores the relationship between artificial intelligence and bone problems, illuminating how AI can revolutionize orthopedics and radiology.

It is becoming increasingly apparent as we negotiate the changing landscape of healthcare that new technologies have enormous potential to revolutionize patient care. The integration of artificial intelligence, in particular, into the diagnosis and treatment of bone problems gives an intriguing prospect for improvements in healthcare. Artificial intelligence has emerged as a potent tool in many fields.

This book covers a wide range of issues. It thoroughly investigates how artificial intelligence can improve knowledge and management of bone fractures, tissue engineering for bone regeneration, deep supervised learning for fracture classification, treatment for osteoporosis, orthopedic care, treatment of spinal disorders, pediatric orthopedics, and diagnosis of bone cancer.

This book will be an essential tool for academicians, students, and healthcare professionals. The book offers a road map for utilizing the promise of artificial intelligence to enhance patient outcomes by digging into the complexities of AI algorithms, deep learning techniques, and their application to bone problems.

I appreciate Dr. Rishabha Malviya and all the authors who contributed to this important work with their commitment and knowledge. I am confident that "Artificial Intelligence for Bone Disorder: Diagnosis and Treatment" will inspire additional investigation and progress in the application of AI in bone healthcare, ultimately proving beneficial to patients and medical professionals worldwide.

I am assured that readers will find this book fascinating and informative information that encourages future research, collaborative efforts, and innovations in bone disorder diagnosis and treatment.

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Preface

Healthcare is one of several sectors that Artificial Intelligence (AI) is revolutionizing. In recent years, AI has demonstrated incredible potential for transforming the diagnosis and management of a wide range of medical diseases. The field of bone problems is one area where AI has a lot of potential.

This book looks into the blending of AI and bone health care. It addresses the various uses of AI in the diagnosis and treatment of bone fractures, tissue engineering, orthopedic care, spinal problems, pediatric orthopedics, bone disease prediction, and imaging for bone cancer through a careful selection of chapters.

Thanks to a thorough analysis of the relationship between bone problems and artificial intelligence, the reader will gain unmatched insight into the most recent developments and prospects. This comprehensive volume proceeds from introductory chapters that provide a foundation in bone fracture detection and tissue engineering to an in-depth examination of the application of AI in particular domains like orthopedics, radiology, and pediatrics orthopedics.

The authors' combined efforts have produced an invaluable resource that connects the fields of AI and bone treatment. The book provides essential insights into the current state and future of AI in bone condition diagnosis and therapy, as well as a methodical examination of machine learning algorithms, deep learning approaches, and their real-world uses.

May this book spark your interest, inspire your creativity, and motivate readers to take advantage of artificial intelligence's promise to advance bone health care and ultimately help people worldwide.

The Authors
October 2023

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Artificial Intelligence and Bone Fracture Detection: An Unexpected Alliance

Abstract
Bone fractures are the most frequent type of injury sustained in accidents. Clinicians mostly use radiographs and CT (computed tomography) scans to diagnose fractures, yet it is frequently impossible to make a correct diagnosis only from images. Also, a lack of doctors in areas where healthcare is scarce, a lack of specialized medical staff in overpopulated hospitals, or pressure caused by a high workload may all make it more likely that a fracture will be misdiagnosed or not heal well. "Artificial intelligence" (AI) is the process of programming computers to act like smart people with little or no human interaction. Using computer vision and AI techniques like deep learning and machine learning for image processing is becoming more and more important for recognizing bone fractures. This chapter begins by discussing bane fracture and its different kinds. Consequently, the function and uses of AI in bone fracture are described. This chapter also discusses various algorithms based on machine learning and deep learning and their importance in bone fracture detection.

Keywords: Artificial intelligence, bone fracture, deep learning, machine learning, radiology, algorithm, fracture detection

1.1 Introduction

The term "artificial intelligence" (AI) is used to describe the practice of utilizing computers to simulate intelligent behavior with little or no input from humans [1]. In addition, recent advances in AI, and notably machine learning and deep learning, have allowed machines to significantly improve their ability to encode and interpret imaging data [2]. In medical science, AI is used for a wide variety of tasks, including symptom identification and radiological im age processing. Machine learning is the iterative process that artificial intelligence utilizes to improve in response to the training technique, further enhancing the outputs for judgments and predictions.

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The learning process involves various types of learning [3]. One type of machine learning, supervised learning, trained itself to anticipate future outcomes using a set of known data [4]. To categorize newly entered data, a trained model is then applied to the data using a classification technique [5]. The resulting groups are then used to make judgments. Unsupervised learning methods are another option that can be utilized to generate judgments in situations where trained models are not available [6]. Data analysis, computation, and application are all part of the learning process [7, 8]. Training in data collection is a common definition of learning. Like how training is a combination of numerous techniques, deep learning is based on supervised and unsupervised learning as well as the use of networks like artificial neural networks. Artificial intelligence is a branch of computer science that automates the process of combing through enormous datasets in search of recurring patterns and trends, frequently in datasets that are utterly unrelated to one another, like medical imaging for the detection of fractures. The application of machine learning and deep learning techniques has significant advantages in the disciplines of image processing, computer visualization, and medicine.

Layered artificial neural networks are the building blocks of deep learning, a subfield of machine learning. Each layer is composed of a predetermined number of units, each of which is a condensed representation of a neuron cell based on the anatomy of neurons seen in the human brain [9]. In specialized tasks, deep learning algorithms can match and occasionally even surpass human performance [10, 11]. Information technology has been revolutionized by deep learning, which has made it possible to quickly solve large-scale, data-driven challenges. The automated classification and detection of proximal humerus fractures using a deep learning algorithm is a prime example of artificial intelligence (also known as machine intelligence) in action, as it uses numerous layers of network systems to obtain features to enhance the quality of perception and accuracy. Deep learning is essential for the computation and processing needed by artificial intelligence. Deep learning uses neural networks, which are made up of input layers and hidden layers, to carry out the necessary computations and processing [12]. As a result, deep neural networks have emerged as a promising tool for improving the efficiency and precision of medical picture diagnosis. Deep learning has been gaining popularity over the past few years [13]. Recent studies have shown that deep learning can do difficult interpretation at the same level as human medical professionals [14, 15]. In the field of orthopedic traumatology, several studies have been carried out using deep learning in radiography to diagnose fractures [16]. However, research on the application of deep learning to CT imaging of fractures is few.

Any kind of bone break, from the tiniest hairline to the most severe severing, is considered a fracture. Fractures can be either closed or open, depending on the severity of the damage. The amount of force required to cause a fracture varies [17]. Both the patient's age and the affected bone region play a role in the degree of severity. Orthopedics is the medical specialty concerned with damaged bones, also known as fractures. Bone fractures can occur in any orientation after being broken by an outside force or stimulation, including but not limited to the vertical, horizontal, and oblique planes. Failure to diagnose a fracture in a clinical setting where specialist knowledge is lacking can have serious effects and reduce the likelihood of a positive result.

In most cases, an X-ray can detect and identify any form of fracture. Fracture confirmation via computed tomography (CT) or magnetic resonance imaging (MRI) can be performed later. X-rays are an electromagnetic radiation-based imaging technology used to provide images of structures beneath the skin. The patient is positioned properly for X-ray imaging of the affected area. Computer tomography, more commonly known as a "CT scan," is a medical imaging technique that employs a combination of a computer as well as an X-ray machine to produce cross-sectional images as well as three-dimensional reconstruction visuals to improve diagnostic capability and image clarity. To create images, magnetic resonance imaging, often known as MRI, makes use of the paired as well as unpaired magnetic fields of the proton nucleus of hydrogen atoms in water, which is prevalent throughout the body. Even if a fracture has not yet caused any noticeable symptoms, an MRI can help find it—for example, stress-related fractures as well as fractures that occur in situations where imaging procedures such as X-rays and CT scans are dangerous to perform during pregnancy. As a result of recent developments in machine learning, it is now possible to employ computers to assist with medical diagnosis, ushering in a veritable renaissance in the scientific community. It uses up-to-date, cutting-edge methods and tools to give a rapid diagnosis with increased precision. If a fracture is not detected on an X-ray, the patient could suffer serious consequences that hinder their rehabilitation.

1.2 Bone Fracture

There are various ways to categorize fractures. Examples of traumatic fractures include those sustained in motor vehicle accidents, physical altercations, train mishaps, slips and falls, and similar occurrences. Bones that have been compromised by cancer metastasis (bony metastasis) or osteoporosis (increased porosity of the bone) are more likely to suffer a pathological fracture. Implant-related fractures occur at mechanical weak points brought on by persistent pressure. Children and teenagers may only have a partial fracture line since their bones are still growing. These fractures, often known as "greenstick fractures," are incomplete due to the failure of one tension cortex. Children may experience a deformation of the bone without a clear fracture line. Numerous other factors, such as fracture pattern, fragment displacement, dislocation or subluxation of adjacent joints, quantity of pieces, etc., can be used in the classification process. The following Table 1.1 summarizes the common breakdowns and compares them across several dimensions.

Figure 1.1 depicts the various types of fractures that might occur. The first type of fracture is known as a stable and closed fracture, and it occurs when the bone fragments are ruled into a straight line and are just slightly out of place. The second type of fracture is known as an open or compound fracture, and it occurs when a bone breaks and protrudes completely through the skin. The bone may be visible in certain circumstances and hidden in others. Afterward, a transverse fracture occurs. An example of a transverse fracture is one in which the fracture line runs at an angle to the body's longitudinal axis. Next is oblique fractures, also called multiple fractures since they occur at different angles. Furthermore, a comminuted fracture occurs when the bone breaks into more than two pieces. Subsequently, a condition known as greenstick fracture occurs when bone fractures but do not fully separate. Kids may feel this way. Finally, spiral fractures occur when a break in the bone progresses in a spiral pattern.

However, only X-rays can correctly identify a fracture [18], even though a visual deformity, particularly a large one, may be discernible to the human eye. To provide a comprehensive description of a fracture, the following information must be provided: the name of the bone, the region of the bone, the pattern of the fracture line, the presence or absence of compression, the existence or absence of displacement of fracture fragments, the type and degree of displacement, the presence or absence of any pre-existing pathology as well as the existence or absence of any associated joint pathology, such as dislocation or subluxation. This information can be found in Table 1.1.

1.3 Deep Learning and Its Significance in Radiology

The term "deep learning" (DL) is utilized to designate a collection of approaches employed in the discipline of machine learning and the much

Table 1.1 Comparison of fractures with diagnosis.

Type of fractures	Symptoms	Diagnosis	Consequences if missed	Possibility of correction
Stable and closed	Pain, swelling, loss of transmitted movements, slight or no deformity	X-rays	Angulation, pain	Yes
Open and compound	Pain, bleeding, open wound, loss of transmitted movements, crepitus, deformity	X-rays	Malunion, infection, non-union, septic arthritis, osteomyelitis, Volkmann's ischemia, compartment syndrome	Less
Transverse	Pain, deformity, swelling, crepitus, loss of transmitted movements	X-rays	Angulation, persistent, stiffness, deformity, malunion, shortening, non-union	Less
Oblique	Pain, deformity, swelling, crepitus, loss of transmitted movements	X-rays	Angulation, stiffness, persistent deformity, malunion, non-union, shortening	Less
Comminuted	Gross swelling, total loss of transmitted movements, severe pain, crepitus, gross deformity	X-rays	Compartment syndrome, neurovascular injury, Volkmann's ischemia, subdeck's osteodystrophy malunion, nonunion	Maybe or may not
Greenstick	Pain, deformity, swelling, restricted mobility, angulation	X-rays	Angulation, stiffness persistent deformity, malunion	Yes
Spiral	Pain, deformity, swelling, loss of transmitted movements	X-rays	Deformity, angulation	Yes

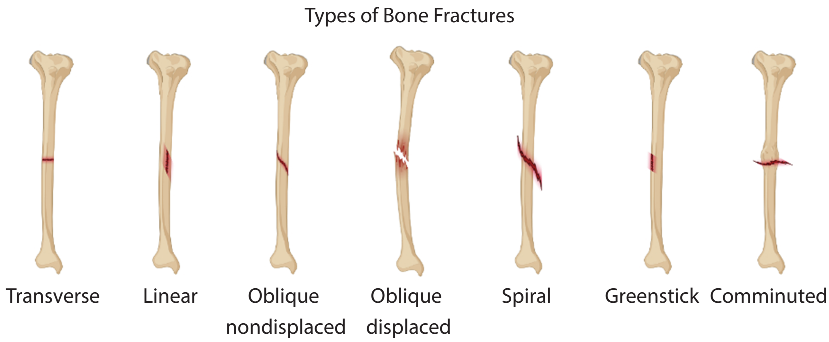

Figure 1.1 Different types of bone fracture.

broader subject of artificial intelligence. Both fields are subfields of the field of artificial intelligence. As a subfield of AI, deep learning is characterized by its reliance on simulated neural networks. The units, which are based on the architecture of the human brain, increase in number with each successive layer. The idea of deep learning revolutionized the field of information technology (IT) by providing large-scale answers to problems that had previously taken hours to resolve. The common goal of these algorithms is to comprehend the information at hand. For semantic image processing applications, deep learning has proven to be particularly effective [19].

Classification, segmentation, and noise reduction in medical images are just some of the many applications of DL approaches in use today. What is more, DL algorithms can learn from previous successes by using a technique known as transfer learning [20]. The significance of deep learning in radiology cannot be overstated. As a result, doctors will be able to give their patients better care and more accurate diagnosis. In the field of fracture diagnosis and localization on medical images such as radiographs and CT scans, deep learning achieves better results than humans under the current conditions [21].

1.4 Role of AI in Bone Fracture Detection and Its Application

As early as 1960, AI was being used to analyze X-ray pictures for medicinal purposes [22]. The data was initially converted to a numerical format for computation and analysis. Computer-aided detection was a later development in AI. Improvements in computational speed can be traced to the maturation of a system's ability to learn from past mistakes; this ability is known as machine learning. The advancement of AI systems in many fields is made possible through machine learning. AI models that undergo training and learning yield outcomes that are both more accurate and more efficient when applied to datasets [23, 24]. Artificial intelligence has proven very effective at sorting urgent situations from less urgent ones.

Bone fractures in X-rays can be identified by artificial intelligence systems that have been trained using machine learning methods. AI-enabled models can provide automatic diagnoses of bone fractures. When applied to X-ray pictures, a neural network that has been trained with appropriate data yields reliable findings. In addition, AI and, more specifically, deep learning, which includes neural networks, enhance the medical research area by allowing for enhanced visualization of imaging data. Bone fracture detection architecture development relies heavily on convolutional neural networks. It can produce results quickly and accurately.

Several studies have demonstrated that deep learning may be utilized to diagnose fractures [25] by undertaking a retrospective analysis to investigate the relevance of transfer learning using deep convolutional neural networks (CNNs), which had been pre-trained on photos that were not related to medicine, to the job of automating fracture recognition on plain wrist radiographs. The authors utilized the inception V3 convolutional neural network [26], which was trained for the IMageNet Large Visual Recognition Challenge on images other than radiography [27]. To complete the binary classification task, the top layer of the Inception V3 network was retrained with the help of a training dataset consisting of 1,389 radiographs annotated by humans. They were successful on the test dataset, with an area under the curve (AUC) of 0.95 (139 radiographs). This proved that the problem of fracture diagnosis on plain radiographs may be effectively applied to a CNN model pre-trained on non-medical pictures. Both the specificity and sensitivity were maximized at 0.90 and 0.88, respectively. Automated fracture analysis techniques like segmentation, edge recognition, and feature extraction have never been as accurate as they are now (prior studies only reported sensitivities and specificities in the 80%–85% range). There are still questions that need to be answered, even though this study proves the premise. At the end of the training phase, it was revealed that the accuracy of the training data and the accuracy of the validation data had a very minor but noticeable difference. Most likely, the problem was caused by excessive tailoring. There are a variety of approaches that can be taken to cut down on overfitting. It is possible to make the process of training more effective by eliminating the influence of attributes that are not important with automated segmentation of the most pertinent region of interest. One such strategy that could assist in lowering the incidence of overfitting is the application of cutting-edge augmentative approaches. In the realm of machine learning, another barrier that frequently arises is the size of the research sample [too small (1,000:10,000)]. The higher the size of the population that is being sampled, the more accurately it will reflect the overall population [28].

The researchers also employed plain AP (perfect anteroposterior) shoulder radiographs to investigate the effectiveness of deep learning in detecting and categorizing proximal humerus fractures. This was done by comparing the radiographs to a database of known fractures. The conclusions of the CNN network were contrasted with those of several specialists (general physicians, radiologists, and orthopedic surgeons). They used a pre-trained ResNet-152 model that was modified specifically for their proximal humerus fracture datasets, which included a total of 1,891 plain AP radiographs. The trained CNN had outstanding ability in distinguishing between normal and broken proximal humeri. On straightforward AP radiographs of the shoulder, the results for the classifying fracture type were also positive. The CNN performed better than primary care physicians and general orthopedic surgeons, and it was on par with shoulder specialists in terms of its effectiveness. This suggests that other fractures and orthopedic illnesses that can be accurately diagnosed with plain radiographs, such as those of the proximal humerus, could benefit from automated diagnosis and classification in the future [36].

The researchers carried out a study to test deep learning's capacity to automatically identify osteoporotic vertebral fractures (OVFs) on CT scans [29]. This evaluation was carried out as part of a retrospective study. The authors developed a machine learning system that relied solely on a deep neural network framework for all its functionality. Their OVF detection method consisted of two primary components: (1) a CNN-based feature extraction module and (2) an RNN (recurrent neural network) module that aggregated the retrieved features and produced the final diagnostic. Both modules were trained using the same data. A deep residual network, abbreviated as ResNet, was utilized to analyze the CT scans and extract the features [30]. For their training dataset, the researchers made use of 1,168 CT scans; for their validation set, they made use of 135 CT scans; and for their test dataset, they made use of 129 CT scans. On an independent test set, their system achieved levels of accuracy and F1 scores (mean of precision and recall) that were equivalent to those of expert radiologists. By eliminating the need for human intervention during OVF screening, this computerized detection system may help reduce false-negative errors in the diagnosis of asymptomatic, early-stage vertebral fractures.

1.4.1 Data Pre-Processing

The dataset can be pre-trained with non-medical pictures and then used for the task of automating fracture identification in plain radiographs. Preprocessing a dataset of broken photos can enhance data attributes and hide undesired aspects [31]. Pre-processing the data for a learning model takes a considerable amount of time. The goal here is to get the data ready for analysis and calculations. Overfitting is a potential issue during data retrieval and selection [32]. Overfitting occurs when the data absorbs irrelevant information, such as noise, during the learning process. The learning process itself takes considerable time, and the initial dataset acquisition is just the beginning. The next step is a labeling procedure that must be carefully supervised. This information is then separated into two groups: fractured and unbroken. The fracture's identification was verified by a surgeon with more than 3 years of experience. An orthopedic specialist's expertise is used to interpret a dataset of X-ray images obtained from a specialized hospital.

1.5 Primary Machine Learning-Based Algorithm in Bone Fracture Detection

Early fracture detection mechanisms relied on the neck-shaft angle (NSA) alone to function. As an example, if the NSA value is less than 116, a fracture is assumed to be present in the image. The mistake rate is close to 8% since the single feature is insufficient for identifying fractures. Therefore, researchers present a novel classification-based approach to detecting mild diseases by analyzing dragging characteristics in femur X-rays and performing the textural assessment of the bony trabecular pattern.

The process of feature extraction is crucial for using foundational machine learning methods for fracture identification. Gabor filters, Markov random field, and intensity gradient direction are techniques used for feature extraction from femur X-rays [33, 34]. Some researchers have exclusively used the Gabor filter for feature extraction while using classifiers for fracture identification [35]. Some scientists employ a gradient transformation using homotopic functions. Regression trees and SVM have several potential applications, including medical diagnosis and weather forecasting [36, 37]. It also expresses one take on the central theme and the supporting issues, disputes, challenges, etc., by analyzing the article's topic considering the overarching theme of the publication and comparing the results to previous or ongoing research or practice in the field.

1.5.1 Ensemble-Based Classification System

To enhance predictions, ensemble approaches combine multiple algorithms into a unified framework. Associating different kinds of learning models helps to refine the results. Since this is the case, ensemble methods are favored over alternative approaches. Ensemble-based classification systems are collections of classifiers that work together to provide a composite output [38]. Unlike the other techniques, which utilize the same learning method for all the datasets, the initial approach to the ensemble methodology is based on applying multiple learning methods on separate training sets. For accuracy, the classifier system combines the results of a small number of base classifiers [39].

To pick the best possible subset of classifiers, ensemble classifiers make use of selection procedures. There are two distinct ways that one can decide between two options: The most efficient classifier would be chosen to be used on the validation data in an entirely static setup. Both dynamic classifier selection and dynamic ensemble selection are valid applications of the dynamic methodology. Dynamic classifier selection uses a set of preselected classifiers as a foundation upon which to build an ensemble. The goal of dynamic ensemble selection is to find the most predictive ensemble combination [40]. Bagging and boosting are two examples of ensemble methods that have medical applications for fracture identification [41].

To better diagnose osteoporotic fractures, researchers have turned to ensemble-based learning techniques like bagging, boosting, and random subspaces [42]. Classifiers are developed from many models, each with its own unique set of properties. Bone fracture detection uses the ensemble method of 10-fold cross-validation [43]. In the research process, feature selection often comes first, followed by using a machine learning strategy. This method has the benefit of preventing additional, redundant bone testing.

1.5.2 Bagging

Bagging is a popular method that uses a single dataset to train many models. Some typical and recurring occurrences are the result of randomly selecting the initial functionality of a distinct dataset from the same dataset k time. Training several related datasets in parallel has many benefits, including reducing training time and enhancing the quality of results for tasks like decision trees that use many datasets. Joining the results of multiple classifiers where the majority value is the same increases precision. It relies solely on the arithmetic mean of results from the various