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Fundamentals of Osteoporosis and the Associated Developments in its Diagnosis and Treatment

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Abstract
Osteoporosis is a disease concerning the bones, where the bones are weakened to the point of breaking. The bones gradually become porous in this condition. The development of this health condition may take a few years and is often noticed when the patient has some sort of fracture. It is considered as the "major public health problem" as it is the most common form of bone ailment in humans. Successful governance of this disease requires a multidisciplinary approach. Implementation of various methodologies, such as artificial intelligence, along with the pharmacological and non-pharmacological approaches in the diagnosis and treatment of osteoporosis has been of great importance in improving and handling this serious malady. Hence, this paper explained the types of osteoporosis and highlighted the implementation of artificial intelligence and digital pathology in the developments of efficiently treating this disease.
Keywords: Osteoporosis, Artificial Intelligence, Digital Pathology, Diagnosis and treatment.

Abstrak
Osteoporosis adalah penyakit yang berkaitan dengan tulang, di mana tulang menjadi lemah sehingga patah. Tulang secara beransur-ansur menjadi berliang dalam keadaan ini. Perkembangan keadaan kesihatan ini mungkin mengambil masa beberapa tahun dan sering diperhatikan apabila pesakit mengalami patah tulang. Ia dianggap sebagai "masalah kesihatan awam utama" kerana ia adalah bentuk penyakit tulang yang paling biasa pada manusia. Kejayaan tadbir urus penyakit ini memerlukan pendekatan pelbagai disiplin. Pelaksanaan pelbagai metodologi, seperti kecerdasan buatan, bersama-sama dengan pendekatan farmakologi dan bukan farmakologi dalam mendiagnosis dan merawat osteoporosis telah menjadi sangat penting dalam memperbaiki dan mengendalikan penyakit serius ini. Oleh itu, kertas kerja ini menerangkan jenis osteoporosis dan menekankan pelaksanaan kecerdasan buatan dan patologi digital dalam perkembangan merawat penyakit ini dengan cekap.
Kata kunci: Osteoporosis, Kepintaran Buatan, Patologi Digital, Diagnosis dan rawatan

Introduction

Osteoporosis is a versatile disorder that is distinguished by low bone mineral density (BMD) and low bone mass caused by the degeneration of bone tissue, along with the severance of bone microarchitecture, which eventually affects the bone strength and escalates the possibility of bone fracture (Hendrickx et al., 2015). Bone density is shown as "grams of mineral per area or volume" which is indicated by peak bone mass and amount of bone loss in all individuals. The peak bone mass signifies the quantity of bony tissue which remains after the full skeletal development has taken place in an individual (Bonjour et al., 2012). Bone strength refers to the combination of bone density and bone quality. The bone quality of an individual is decided based on the construction, turnover, microfractures and mineralization of the bone (NIH Consensus Development Panel on Osteoporosis Prevention, Diagnosis, and Therapy, 2001). Despite other skeletal anomalies, according to World Health Organization (WHO), BMD should be considered as the main factor for diagnosing osteoporosis (Cruz et al., 2018). About 158 million elderly people, with an age more than 50 years, are more prone to get fractures from osteoporosis. Moreover, it is seen mostly in the hip, wrist, spine and humerus of the affected body, called the Major osteoporotic fractures (MOFs). Hip fractures often lead to a high risk of death in patients within a year, putting this disease in the category of fatal maladies. Thus, it could be concluded that anyone with a previous fracture could be exposed to a forthcoming worse fracture (de Vries et al., 2021).

There are two mechanisms of bone development: a) endochondral ossification and b) intramembranous ossification. The first one is the process by which

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long bones, such as the femur, are formed. In adults, this approach also helps in healing fractures as it involves the osteoblasts and vascularization of the ossifying tissues. Ossifying tissue, such as mesenchymal tissue, transforms into cartilage which eventually grows into long bones in endochondral ossification. In contrast, when these mesenchymal tissue precursors change into flat bones of the skull, clavicle and most of the cranial bones, the procedure is called intramembranous ossification (Tong et al., 2019; Kirby & Young, 2018; Breeland & Menezes, 2020). Here, the bones are directly deposited on thin layers of connective tissues, usually found on the top of the skull (Lonergan et al., 2019).

The pain starts only when the affected area is broken. Caucasians, women, and older people are always at higher risk of ending up with this disease. The best way to ensure the prevention of this disease is by doing physical activities every day starting from childhood, along with eating proper nutritional food and drinks that aid in developing healthy bones, such as eggs and milk. This is because as a child grows, even moderate physical exercise and intake of a healthy diet can play a crucial role in maintaining the healthy muscles and bones of that individual (Sozen et al., 2017; Sinaki, 2021). Osteoporosis can be divided into two, primary (idiopathic) osteoporosis and secondary osteoporosis. Primary osteoporosis is very common in women who have undergone menopause, also known as postmenopausal osteoporosis. The senile version of it is developed in men, where bone remodeling is significantly diminished (Ortner, 2003). Secondary osteoporosis is also called steroid or glucocorticoid-induced osteoporosis because these patients have either a hormonal imbalance or may contract any chronic disease from glucocorticoid medication which results in increased shedding of bones (Iliou et al., 2014).

Generally, the risk of osteoporotic fracture highly relies on peak bone mass, which is achieved at the age of 25 years. Later this peak bone mass tends to stay the same until the age of 55 years, and then start to alleviate when age-related bone loss begins. Therefore, an individual should focus on building the peak bone mass while growing up, as it lessens the risk of having fragile bones later in life compared with individuals who end up with low bone mass after fully growing up (Hendrickx et al., 2015). Moreover, after completing the longitudinal growth, about ten per cent of the bone undergoes remodelling, which is an unceasing anatomical process of the human body where the osteoclasts remove the old bones and osteoblasts cause the formation of the new bones to replace the lost portion. The bone remodeling process is important because the terminal differentiation of osteoblasts into osteocytes- in the mineralized bone tissue- does the job of detecting microcracks, mechanical strain and any possible fluctuation in the hormonal habitat of the bone. Furthermore, it helps in repairing any microdamage, preserves the bone weight and mineral homeostasis. Even though bone remodeling takes place in humans all the time, regular bone loss still takes place due to hormonal or genetic changes, ageing, or lifestyle background (Owen & Reilly, 2018).

Modern technology, such as in digital pathology, has aided to combat diseases like osteoporosis more effectively. Digital pathology integrates pathology information, management and sharing in a digital environment. This is done to obtain digital images of high quality via computer devices and incorporates using of glass slides containing samples, which can later be converted into a digital scan (Doolan et al., 2019). Digital pathology can produce stationary images that can be live-streamed and removes the need for a pathologist to spend time on a traditional microscope by digitizing the entire glass slide of the respective sample. Simultaneously, Artificial intelligence incorporates machine learning and deep learning algorithms to come up with imaging tools that can help obtain better pathological image that would, in turn, make diagnosing the stages of osteoporosis much easier than it was before. This means that artificial intelligence (AI) can be integrated with digital pathology to get a better outcome (Ferizi et al., 2019). For example, in oncology, AI and digital pathology is being mixed to acquire a higher degree of precision and accuracy in digital image examination (Colling et al., 2019). Even though it is costly to fully rely on digital pathology, and a bit complicated to fully implement it clinically by technophobic pathologists, digital pathology is increasingly becoming more popular among scientists to deal with diseases in a more efficient manner (Hanna & Pantanowitz, 2019). It can also help in a better diagnosis of osteoporosis that could aid in finding a better treatment for this disease. In this paper, a comprehensive discussion on osteoporosis was conducted. The conventional methods to diagnose and treat this disease have been briefly highlighted. Moreover, the incorporation of medical biotechnology, digital pathology and artificial intelligence were introduced to emphasize the up-to-date developments achieved in combating this malady.

Types of Osteoporosis

Primary Osteoporosis

Primary osteoporosis includes complicated pathogenesis which can be affected by both environmental (noninheritable) and genetic determinants. It not only involves age-related factors, such as oxidative stress and apoptosis, but also occurs in postmenopausal women, hence, also called postmenopausal osteoporosis (Marcucci, 2015). After menopause, women have an inadequate amount of oestrogen in their bodies, which debilitates the normal bone turnover cycle, decreasing the osteoblastic process and increasing osteoclastic resorption activity. This means that more bone gets resorbed than deposited, resulting in a net loss of bone. Women mainly suffer from bone loss in two main phases. The first phase is where the decrease in available oestrogen in the body causes excessive bone loss, especially the trabecular bone, which can also be referred to as menopause-related bone loss. The second phase is called age-related bone loss, as it is also witnessed in elderly men. This usually happens after four to eight years of the first phase of bone loss in women, where the constant and stagnant loss of trabecular and cortical bones are seen (Ji & Yu, 2015).

On the other hand, oxidative stress can also lead to primary osteoporosis in adults. Oxidative stress is defined as the imbalance between the production of free radicals and the antioxidant systems, resulting in an increase in the number of reactive oxygen species (ROS) in the body (Betteridge, 2000; Domazetovic et al., 2017). Oxidative stress increases with age and is responsible for the depreciated bone formation and bone mass deficiency correlated with both ageing and the growth of osteoporosis. Besides, apoptosis is also believed to cause osteoporosis. Cell apoptosis is an important process in every step of an organism's growth phase because it can remove poorly working and likely cancerous cells later in life. Nevertheless, as an individual grows older, the capacity of regulation of this important cell process is affected, contributing to osteoporosis. The main reason this happens is due to the cessation of osteocytes, which significantly affects the brittleness of the bone, as these cells cannot contribute to the repairment and preservation of the bone health and mineral homeostasis (Hendrickx et al., 2015; Marcucci, 2015).

Noninheritable factors, such as lifestyle and environment, always play a crucial part in inducing osteoporosis in humans. For instance, vitamin D is an essential nutrient needed for the growth and development of healthy bones. Therefore, a little bit of exposure every day to the sun is harmless. Besides, calcium and phosphate are also important elements that are regulated by vitamin D, which conduces in bone formation, mineralization, and resorption, decreasing the fracture risks. Furthermore, genetic factors such as single nucleotide polymorphisms (SNP) that causes polygenic osteoporosis, along with monogenic conditions such as osteogenesis imperfecta, can also cause osteoporosis (Hendrickx et al., 2015). SNP is a type of polymorphism demonstrating alteration at a single point in a DNA sequence among organisms (Vallejos-Vidal et al., 2019). Osteogenesis imperfecta is an idiopathic genetic malady where the bones fracture easily as the growth of collagen bone is affected (Curtis, 2019). This connective tissue disorder leads to low bone mass and fracture, which can happen at any age and in any gender (Alharbi, 2015).

There are also two more types of osteoporosis that are rare. The first one is called juvenile idiopathic osteoporosis, where the primary bones such as the scapula and clavicle get demineralized. It is idiopathic because its specific predominance is unknown. It starts from a prepubertal age. And even though the exact pathogenesis is unidentified, it is usually characterized by low bone formation and abated cancellous bone volume (Imerci et al., 2015). The next one is known as pregnancy and lactate-associated osteoporosis. In this case, vertebral fractures are observed in women either a few days before giving birth or during the postpartum period. It is diagnosed by checking clinical history and backed by imaging results of any possible vertebral fragility fractures (Zhang et al., 2017).

Secondary Osteoporosis

Secondary osteoporosis usually emerges from other diseases such as anaemia or malabsorption, or from undergoing medications such as corticosteroids for rheumatoid arthritis or chemotherapy to treat cancer (Sheu & Diamond, 2016). It can be found in men and pre-and postmenopausal women. It is not as prevailing as primary osteoporosis, and when treating this disease, it is advised to ignore its secondary causes because each patient may require different treatment. For an improved response, it is better to acknowledge the underlying disorder and then treat it. For example, a postmenopausal woman with hypercalciuria will have increased gain in bone mineral density (BMD) when receiving a bisphosphonate along with indapamide to cure the hypercalciuria compared to patients who only intake bisphosphonate. Moreover, some drugs may lead to bone loss and fractures, such as Antidepressants and Thiazolidinediones. Hence, bone health should be looked upon before prescribing these remedies for

diseases that may lead to secondary osteoporosis (Mirza & Canalis, 2015). The widely known causes of secondary osteoporosis are endocrine disorders, malnutrition, gastrointestinal ailments, and haematological maladies (Colangelo et al., 2019).

Firstly, endocrine disorders such as hyperthyroidism and hypothyroidism may lead to secondary osteoporosis. Hyperthyroidism boosts bone turnover, whereas hypothyroidism declines the bone remodeling cycle. Hence, the skeletal resistance is affected (Colangelo et al., 2019). Additionally, hypogonadism is the most prevalent cause of secondary osteoporosis in men, as lack of testosterone is distinctly correlated with bone loss and weakness (Golds et al., 2017; Rochira et al., 2018). Bone fragility is also seen in patients suffering from prolactin-secreting adenoma, where bone quality is affected and fractures may appear in bone mineral density that is either normal or a little lower than normal (Mazziotti et al., 2018).

Next, eating disorders or malabsorption is also known to play a key role in causing secondary osteoporosis in both males and females. Poor nutrition means scanty availability of essential proteins, vitamins, and minerals. Vitamin D and minerals are very important for the maintenance of healthy bones, and lack of these in the body means the bones are more prone to fractures and shedding, as there will be decreased calcium absorption in the small intestine (Laird et al., 2010; Balk et al., 2017). Anorexia also leads to slow bone accumulation during development and low peak bone mass (Drabkin et al., 2017). On the other hand, obesity, where the body mass index (BMI) of a person is high, can also be a reason for bone fragility as the excess fat and abdominal adipose tissue produces pro-inflammatory cytokines and adipokines that adversely affect bone metabolism whereby bone development is attenuated and bone resorption is promoted (Li et al., 2017; Kurgan et al., 2020).

Other than eating disorders, gastrointestinal disorders such as inflammatory bowel disease (IBD) are also known to increase the possibility of vertebral fractures. This is because the IBD patients already suffer from inflammation, hypogonadism, or is in taking corticosteroids which negatively influence the bone microstructure and the skeletal system (Pepe et al., 2017). Moreover, patients diagnosed with chronic liver disease are also at high risk of getting secondary osteoporosis because damaged livers often have impaired osteoblast function, high bone resorption due to elevated levels of bilirubin and bile, and systemic inflammation due to fatty liver disease, where all these reasons cause the bones to become weak and frangible (Colangelo et al., 2019).

Lastly, haematological illness such as β-Thalassemia major is also held responsible for causing secondary osteoporosis, as this inherited disorder concerns the improper synthesis of haemoglobin. Numerous determinants cause osteoporosis in thalassemia. For instance, lagging in sexual development, iron chelators, or iron toxicity can precede thalassemia (Voskaridou & Terpos, 2008). This means the affected patient suffers from anaemia and skeletal malformation and requires daily transfusions along with chelation therapy to survive. β-Thalassemia major also causes marrow hyperplasia (surge in the number of haematopoietic cells) and leads to endocrine complications, eventually affecting bone health (Chen et al., 2018; Piga, 2017).

How Does Osteoporosis Look Like?

Before the development of osteoporosis, the stage where the bone starts to decay is called osteopenia, which is a primary stage, and early preventive measures, such as healthy eating, maintaining proper body weight, and consuming a good amount of calcium and protein can alleviate the hazard of development of osteoporosis (Peterson, 2001). Generally, osteopenia matures into osteoporosis when the new bone tissue formation cannot keep up with the loss of the existing bones. This disease is often considered to be a normal part of ageing; however, females are more exposed to being affected after several years of their menopause. Furthermore, both males and females can get osteoporosis if they do not exercise regularly, have the habit of excessive smoking or drinking, or have low body mass index (BMI) (Keen, 2007).

The normal bone of an individual is usually mineralized and has smaller holes or pores in the bones. In the process of development of osteoporosis in an individual, the bones gradually develop the pore size, leading to bone fragility and bone fracture. Severe osteoporosis occurs when the pore sizes are too big in the bone tissue to keep it upright anymore, leading to extreme fracture. According to Marx (2018), a healthy bone has osteoblast cells that regularly generate new bones, while the osteoclast cells break down and take in the old bones. This is how the bones are regulated to keep healthy. However, in an unhealthy bone, the osteoclasts often do not breakdown, and rapidly become very hard in texture. The retainment of this set of bone tissue may result in the breaking or losing of blood supply. Thus, the bones start to deteriorate by the process known as

osteonecrosis (Marx, 2018). Osteonecrosis is a condition where impairment of the blood supply in a localised area of the bone leads to bone necrosis. To put it simply, the bony tissue of that area dies. This usually happens when mechanical injury leads to bone damage and fracture. The development of osteonecrosis is predominant in skeletal areas where blood circulation is restricted (Steinberg & Steinberg, 2015; Cullen, 2010).

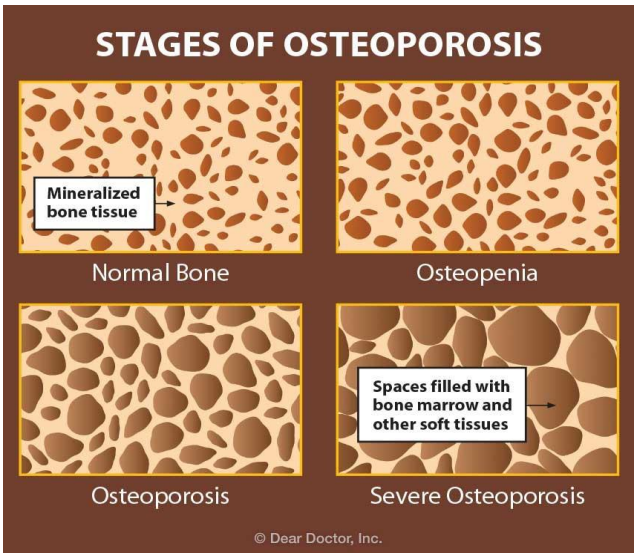

Figure 1: *General overview of the steps in the development of Osteoporosis. The normal and mineralized bone tissue gradually become porous containing bone marrow and other soft tissue. Obtained from Marx. (2018).*

Conventional Treatment of Osteoporosis

Considerable development and changes are ongoing to provide better management of osteoporosis. Fracture risk can be reduced by seventy percent when adults with risk for fracture are treated beforehand. Moreover, this type of secondary prevention can also alleviate both fracture risk and fatality (Lim & Bolster, 2015). The treatments available can be divided into pharmacological and non-pharmacological treatments.

Pharmacological Treatment

The main target of implementing pharmacological treatment is to decrease the possibilities of bone fractures. To reach this goal, the medicinal prescription has been classified into two groups: a) antiresorptive treatment to alleviate excessive bone resorption, and b) anabolic therapeutics to escalate bone formation. In the management of postmenopausal osteoporosis, the first-line options could be drugs such as risedronate, alendronate, etc., with alternatives of raloxifene drugs for younger postmenopausal women. For men who have had a fresh hip fracture, zoledronic is recommended, while the ones having gastrointestinal complications should undertake non-oral therapy, and men with a high risk of fracture must take teriparatide. Bisphosphonate has been suggested for men under 40 years of age and women with menopause, where both have glucocorticoid-induced osteoporosis (Tu et al., 2018). Another interesting study also found that Urolithin A (UA), a biologically active metabolite produced by gut microbiota, which is involved in the suppression of metabolic pathway known as Receptor Activator for Nuclear Factor-κB Ligand (RANKL)-triggered osteoclastogenesis, greatly aids in the depletion of systemic bone loss (Tao et al., 2021). All the treatments are advised case-to-case, relying on the medical and lifestyle information of each individual patient (Body et al., 2010).

Non-pharmacological Treatment

As the name suggests, non-pharmacological measurements do not deal with prescribing medications. Instead, it focuses on other types of measurements, such as, sufficient consumption of calcium and vitamin D, conducting regular exercises to keep weight under control, reducing or slowly end smoking, refrain from excessive intake of alcohol, or undertake fall-prevention activities, such as Whole-Body Vibration training (WBV) that includes standing or lying on a vibrating platform instead of doing exercises that may increase the risks of falls (Harijanto et al., 2021). These may also be considered as early prevention steps to hinder the worsening of osteoporosis if diagnosed at an early stage, as it may provide with short term advantage over medical treatment for relieving pain in both genders (Body et al., 2011; Gielen et al., 2013). Additionally, continuing the aforementioned healthy habits from an early age may even save one from getting diagnosed with this disease in the first place.

The Fusion of Artificial Intelligence (AI) and Medical Biotechnology in Better Diagnosis of Osteoporosis

Medical biotechnology often involves genetic and hereditary investigations when treating a malady, and high-quality results with high accuracy could be obtained with the aid of Artificial Intelligence (AI) technical tools. Artificial intelligence is the science of designing intelligent machines incorporated with machine learning to build smart computer programs (Kersting, 2018). The modern scientific community has been fusing artificial intelligence with medical science to get better results in the diagnosis and treatments of diseases. Computer and machine

learning are two disciplines seen to go together in the pathology field as well. For instance, drug design and discovery are important sections of the technical side of medical biotechnology that deals with bioinformatics which can handle, investigate, translate, and store the organic data of biochemicals with the cooperation of software engineering to understand the natural sources of the compounds. This, in turn, benefits in coming up with solutions to diseases and infections, speeding up clinical trials (Prasad, 2019).

Artificial intelligence can be applied in medicine discovery and clinical trials, diagnosis of malignant diseases, better radiotherapy, and radiation treatment of patients, produce very effective drugs, manage medication of patients in a clinic or a hospital, and help medical stores keep proper track of the drug sales to increase their sales performance (Prasad, 2019). Thus, it can be realized that artificial intelligence is highly influencing the medical biotechnology field. Engineers can teach machines to learn to diagnose by applying the necessary algorithms of Machine Learning, which means converting real-life disease examples into digital format. This way, the machine already knows the basic diagnostic information before a doctor must examine the patient, which saves time in confirming a pathology, for example, machines can use CT scans to detect strokes or cancers or produce images of eyes or skin to declare what exactly the problem is with the patient (Schmitt, 2019). Therefore, the decisions made by physicians are computer-based, and such medical informatics have expedited the improvement of the intricate system of biomedicine in battling any ailment.

The amount of positive change that has been brought into the field of osteoporosis, by the contribution artificial intelligence and medical science, is impossible to deny or ignore anymore. Various studies have shown that Artificial Intelligence has significantly contributed to the development of diagnosing osteoporosis. One experiment by Yamamoto et al. (2020) implemented deep learning to detect and classify osteoporosis from radiographic results from teeth, spine, hand, wrist, and hip joints, and assess if combining clinical data with imaging technology will boost the diagnostic performances of the machines. AI tool, called the EfficinetNetb4, which is a Convolution Neural Network (CNN) model, was used to do the initial screening of the patients and interpret the resulting radiographs. CNN models are computer-based models that can be used to obtain better radiographic images for easier diagnosis (Albawi et al., 2017). The study found out that the screening and diagnosis rate using this method was more than 80% accurate in clinical trials when compared with other CNN models such as ResNet34 and GoogleNet (Yamamoto et al., 2020). A separate study tried to build and differentiate between the four selected unconventional and modern models to predict the danger of getting MOF from prior fractures. This was done to come up with a tool that could assess the risks related to the probability of getting osteoporosis in the future, from the osteopenia stage, which would greatly help in starting early treatments from reducing the risks of osteoporosis (Vries et al., 2021). Additionally, Iliou et al. (2014) proposed a methodology that comprised of various machine learning techniques, such as computational model Artificial neural networks (ANN) and Intelligent medical Diagnostic systems (IMDS), to help physicians predict osteoporosis based only on the age and weight, rather than carrying out bone densitometry testing. This methodology highly depended on artificial intelligence methods to predict future risks of osteoporosis, which turned out to be easier in implementing compared to scanning the bone density in the bone densitometry method. Generally, the bone density test is done when the bone becomes very fragile or when the patients have already been diagnosed with osteoporosis, by measuring of the remaining calcium or bone mineral density (BMD) of the patient. Contrariwise, the ANN program distinguishes between an osteoporotic patient and a healthy individual, while the IMDS executes initial screening for osteoporosis, giving the same output as the exhausting procedures of bone densitometry (Devikanniga & Raj, 2018). Thus, it can be established that AI can help in easier and increased rate of identifying osteoporosis, as the tool has more than 90% accuracy in detecting future risks of osteoporosis (Rowe, 2020).

AI can also enforce various methodologies to help in pre-determining groups of individuals who are at risk for osteoporosis and fractures. For analyzing BMD and fracture risk, computed tomography, ultrasonography, and magnetic resonance imaging (MRI) are common techniques. For instance, one study demonstrated that MRI is a non-invasive method that can scan the nearest bone area within a very short time (Chang et al., 2017). Moreover, the primary role of these techniques is to distinguish and diagnose fractures, and identify the mass of lost bone, such as in vertebrates or femur (D'Elia et al., 2009). To assess the mineral content of the whole skeleton or only a portion of it, absorptiometry of single and double X-ray is applied. Additionally, the "gold

standard" is the Dual-energy x-ray absorptiometry (DXA) as it is the most advanced, is technically most valid and exhibits high efficiency in determining fractures (Dimai, 2017). The only limitation it shows is the emission of ionising radiation. Fracture risks can also be evaluated by quantitative ultrasonography (QUS) that calculates the broadband ultrasound debilitation and velocity of the sounds, generally computed at the patient's heel. Although MRI does not give information on BMD, it does exhibit some resolution of the internal structure of spongy bone (Ao et al., 2020). Lastly, computerised quantitative tomography (TQC) uses x-ray emission to capture high-definition images via transverse radiographs, where the computer processes the image by forming a chain of photographs detailing the part under study (Cruz et al., 2018).

Along with the improvement of diagnosing osteoporosis with the assistance of AI, the treatments have enhanced too. This can be seen in the application of AI and bioinformatics in designing and discovering new drugs for keeping osteoporosis under control, which is a crucial part of treating this ailment. For instance, new drugs have been discovered for osteoporosis treatment by critically analyzing occasional bone ailments and bone cell biology, such as Abaloparatide and Robosozumab, which are osteoanabolic that help in boosting bone mass (Khosla & Hofbauer, 2017). Furthermore, AI is hugely contributing to the discovery of new and better methodologies that lie beyond X-ray imaging in assessing the bone health, which in turn, helps in diagnosing and treating osteoporosis. For instance, implementation of bone acoustics to interpret bone health, or utilizing dental radiographs to assess jaw osteonecrosis and BMD are alternative ways of diagnosing and treating osteoporosis (**Figure 2**) (Scanlan et al., 2018; Kim et al., 2018). Thus, it is quite evident that recent medicinal fields are very much dependent on AI and digital pathology to provide better medical diagnosis and care.

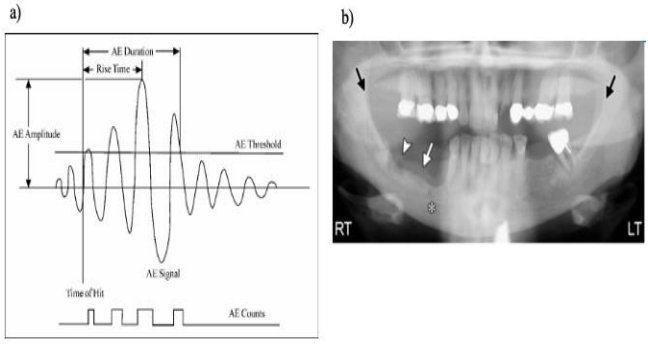

Figure 2: *Implementation of Artificial Intelligence (AI) in assessing bone quality. Both types of assessment help in understanding the bone health of an osteoporotic. a) Bone acoustics of a patient, seen in the form of waves (Shrivastava & Prakash, 2009), b) Radiograph of osteonecrosis of the jaw exhibiting the health of the bone teeth (AlDhalaan et al., 2020).*

Conclusion

Osteoporosis is an ancient disease, and there have always been improvements in the diagnostics and treatment of this malady. In recent years, artificial intelligence in digital pathology has been revolutionising in keeping this disease under control and reduce the risks of building osteoporosis, from osteopenia, in patients. The developments in AI-based diagnostics have concurringly helped in the better treatment of patients of various ages. It is hoped that the development of AI machines will keep ongoing while it also upkeeps solving medical problems with ease and high accuracy than ever before, and that it continues to provide more of such solutions to recognize and medicate other diseases that need attention as well.

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