GMR
The Original

# INTEGRATING QUANTITATIVE BONE IMAGING AND FUNCTIONAL PHYSIOTHERAPY ASSESSMENTS FOR EARLY DETECTION AND MANAGEMENT OF DEGENERATIVE SPINE DISORDERS

**Dr. Katta praveen kumar[1*], Dr Debdeep Karak[2], Vijay Gujar[3], Ashish Kumar Shukla[4], S. Banumathi[5], Carlin Jersha Rachel J[6]**

[1] Jr 3, MD Radiodiagnosis, Shri Sathya Sai Medical College and Research Institute, Pincode: 603018, Email Id: dr.praveenkatta03@gmail.com, Orcid Id: 0009-0007-0349-8114,
[2]Senior Resident, Orthopedics, West Bengal University of Health Sciences, Kolkata, West Bengal 700064, India, Email: debdeepkarak@gmail.com, Orcid Id: 0000000233090992
[3]Associate Professor, MD in Anatomy, Mahatma Gandhi Institute of Medical Sciences, Sewagram, Wardha, Email Id: vijaygujar@mgims.ac.in, Orcid Id: 0009-0000-9277-9557
[4]Professor, Department of Radiodiagnosis, Santosh Medical College, Ghaziabad (NCR), Santosh Deemed to Be University, Ghaziabad (NCR) India, Email Id: drashish07@rediffmail.com , Orcid Id:0000-0002-3232-5382
[5]Assistant Professor, Physics, V.S. B Engineering College, Pincode- Karur-639111, Tamil Nadu, India. Email Id: banukaviyaclm@gmail.com, Orcid Id- 0009-0004-9106-9616
[6]Senior Assistant Professor, Specialization in Physiotherapy, Dr. MGR Educational and Research Institute, Chennai, Pincode:600077, Orcid Id- 0009-0000-5590-9148, Email Id: carlinjersharachel.physio@drmgrdu.ac.in
*Corresponding Author: Email Id: dr.praveenkatta03@gmail.com

## ABSTRACT
Spine degeneration is one of the most common causes of musculoskeletal pain, disability, and decreased quality of life globally. The combination of spine degeneration, osteoporosis, and functional impairment creates diagnostic difficulties that require special attention to be paid to the development of appropriate assessment methods. The present study is devoted to the review of the existing scientific research on the use of quantitative bone imaging and functional physiotherapy tests to diagnose and manage spine degenerative disorders. To this end, peer-reviewed publications and clinical cases were analyzed in order to identify the developments in imaging techniques, bone quality evaluation, functional tests in physiotherapy, and diagnostics. The conclusions show that quantitative imaging modalities, including DEXA, QCT, MRI, and advanced imaging biomarkers, give useful insights into vertebral integrity, bone quality, and structural degeneration. On the other hand, physiotherapy assessments of posture, mobility, muscular strength, balance, gait, pain, and disability supplement imaging findings through evaluation of the clinical impact of structural alterations. Integration of structural and functional assessments increases the diagnostic accuracy, allows for risk stratification, and facilitates the development of a personalized rehabilitation plan. Moreover, modern technologies such as AI, radiomics, wearables, and tele-rehabilitation systems bring new perspectives to precision spine care. Thus, combining quantitative bone imaging and physiotherapy functional assessment can be considered a basis for improvement of early diagnosis, rehabilitation, and treatment of spine degeneration disorders.

**KEYWORDS:** Degenerative spine disorders; Quantitative bone imaging; Physiotherapy assessment; Osteoporosis; Rehabilitation.

## 1. INTRODUCTION
Spinal degeneration disorders are one of the most common orthopedic diseases throughout the world, being the main reasons for chronic pain and disability. These diseases include a wide variety of pathological processes that occur in the intervertebral discs, vertebrae, facet joints, ligaments, and muscles of the spine. The development of the increased incidence of spinal degeneration has been associated with ageing, a sedentary lifestyle, obesity, stress at work, and an increase in life expectancy. Spinal degenerative disorders often lead to chronic neck and low back pain and radiculopathy, creating a significant socioeconomic burden due to healthcare costs, absenteeism from work, and disability. The progress of diagnostic approaches has highlighted the significance of early diagnosis and comprehensive assessment for improving patient outcomes [1].
Ageing is one of the primary factors that cause spinal disorders and their aggravation. Age-associated factors include dehydration of intervertebral discs, a decrease in the height of discs, degeneration of facet joints, loss of muscle mass, and changes in the biomechanics of the spine. Osteoporosis, in turn, leads to low bone strength of vertebrae, making individuals prone to vertebral fractures, spinal deformities, and pain. The combination of osteoporosis and degeneration of the spine is especially widespread in elderly people, as age-related deterioration and bone fragility can exacerbate each other. With the increasing average age of populations worldwide, the incidence of degenerative diseases of the spine will rise significantly [2].

Early detection of degenerative spinal disorders is difficult since structural changes tend to happen slowly and do not necessarily correspond to the degree of symptoms. While many people show no symptoms despite having radiological evidence of degeneration, others suffer from severe symptoms with only minimal degenerative structures. Symptoms of spinal degeneration may also coincide with symptoms of other disorders of the musculoskeletal system and nervous system, thus making the process of diagnosis more difficult. Screening for these types of cases needs a holistic approach that involves clinical assessment, patient history, and testing. A system that employs warning signs when screening patients has become common in distinguishing spinal degenerative problems from the serious spinal diseases that need prompt medical attention [3].

The development of imaging technology in medicine has had an immense influence on the way degenerative spinal conditions can be assessed by virtue of making the visualization of spinal structure possible. The objective data concerning bone mineral density, vertebral shape, intervertebral disc degeneration, spinal deformities, and musculoskeletal tissue health can be obtained through the use of quantifiable imaging methods. With the aid of technologies such as dual-energy X-ray absorptiometry, quantitative computed tomography, and magnetic resonance imaging, it has become increasingly easier to identify pathological features before any functional deficits arise [4].

Whereas imaging assists in detecting structural problems, functional assessment in physiotherapy provides valuable information on the influence of structural changes of the spine on bodily functions like movement, balance, muscle strength, mobility, and activities of daily living. Functional assessment allows to detect the impairments that cannot be detected simply by analysis of the results obtained with the use of imaging methods and creates the basis for planning the individual rehabilitation program. Physiotherapy assessment typically involves assessment of posture, mobility, muscle function, gait, balance, and disability. Functional assessment is an important instrument for monitoring the progress of the patient and optimizing his treatment. Functional assessment has gained wide recognition as a vital part of musculoskeletal treatment recently [5].

A comprehensive diagnosis strategy that takes into account structural, functional, and biological perspectives is necessary for degenerative spine disorders. The management strategy through rehabilitation has proved the usefulness of blending the clinical and functional diagnoses to achieve better results [6]. Similarly, developments in the area of biomarkers have shown the possibility of utilizing objective biomarkers to identify disease changes even before there is any manifestation of clinical signs [7]. Orthopedic biomarker technology developments have also underlined the need for combination of various sources of diagnostic information [8].

The combination of quantitative bone imaging with functional physiotherapy tests, thus, represents a potential approach for increasing diagnostic accuracy and initiating early intervention in degenerative spine disorders. This review attempts to explore the scientific literature on the use of quantitative bone imaging and functional physiotherapy tests in early detection and treatment of degenerative spine disorders. The importance of quantitative imaging methods, bone quality assessment, functional physiotherapy testing, and other multi-disciplinary approaches has been highlighted in particular.

## 2. METHODOLOGY

The current investigation adopted the method of a comprehensive review to assess the role of quantitative imaging of bones and physiotherapy functional evaluation for the early detection and management of degenerative spine conditions. The related literature has been selected through peer-reviewed journal publications, reviews, clinical guidelines, and reputable academic literature available on databases like Google Scholar, DOAJ, and ScienceDirect. A systematic search strategy has been employed using relevant combinations of search terms like degenerative spine disorders, spine degeneration, low back pain, cervical degeneration, quantitative bone imaging, MRI, DXA, QCT, physiotherapy evaluation, rehabilitation, osteoporosis, bone quality, radiomics, and artificial intelligence in spine health care. Literature on non-spinal musculoskeletal disorders, without any connection with degenerative spine disorders, was excluded. The literature selected was then divided into main themes, namely, epidemiology and pathophysiology of degenerative spine disorders, quantitative imaging modalities, bone quality and osteoporosis, physiotherapy function tests, correlations between imaging results and functional impairment, and new modalities for diagnostic and therapeutic purposes. Evidence from the studies included in the review was narratively synthesized in order to understand the existing evidence, its applications, limitations, and future directions. Figure 1 below illustrates the steps undertaken in identifying, selecting, classifying the literature, and synthesizing evidence in this review.


**Figure 1. Overview of the Comprehensive Review Process**

## 3. RESULTS

### 3.1 Degenerative Spine Disorders: Pathophysiology and Clinical Burden

Degenerative conditions affecting the spine are one of the most common causes of chronic musculoskeletal pain and dysfunction worldwide, especially in elderly people. This condition is characterized by degeneration of intervertebral discs, facet joints, vertebral plates, and soft tissue structures, leading to impaired biomechanics and function of the spine. Lumbar and cervical degenerations are the most frequent forms, and are often accompanied by low back pain, neck pain, radiculopathy, reduced range of motion, and a poor quality of life. In addition to aging-induced degeneration of spinal structures, osteoporosis and fragility of vertebrae play an important role in disease progression. The knowledge of pathophysiology of spinal degeneration is important in terms of diagnostic approaches and rehabilitation. The features of common degenerative spine conditions are presented in Table 1.

**Table 1. Major Degenerative Spine Disorders and Clinical Characteristics**

| Disorder | Primary Pathological Changes | Common Symptoms | Functional Consequences | Typical Imaging Findings | Key Reference |
|---|---|---|---|---|---|
| Lumbar Degeneration | Disc degeneration, facet arthropathy, ligament hypertrophy | Low back pain, stiffness, radiculopathy | Reduced mobility and disability | Disc space narrowing, osteophytes, stenosis | [9] |
| Cervical Degeneration | Disc degeneration, osteophyte formation, spinal cord compression | Neck pain, upper-limb symptoms, myelopathy | Impaired neck function and balance | Foraminal narrowing, cord compression | [10] |
| Degenerative Disc Disease | Disc dehydration, annular fissures, loss of disc height | Discogenic pain | Activity limitation | Disc height loss, Modic changes | [11] |
| Facet Joint Degeneration | Cartilage erosion and joint hypertrophy | Axial spinal pain | Reduced spinal flexibility | Facet hypertrophy and sclerosis | [12] |
| Osteoporotic Vertebral Changes | Reduced bone strength and microarchitectural deterioration | Vertebral pain and fractures | Kyphosis and disability | Compression fractures | [13] |

### 3.2 Quantitative Bone Imaging in Degenerative Spine Disorders

Quantitative imaging techniques are essential for early detection and characterization of degenerative changes in the spine. Standard radiographs still serve their purpose in terms of spinal alignment and vertebrae deformations. However, DXA and QCT give valuable data about bone mineral density and vertebrae bone quality. MRI serves as the most informative method since it allows seeing the condition of intervertebral discs, nerves, bone marrow, and paraspinal muscles. In addition, more advanced technologies like diffusion kurtosis imaging, quantitative MRI, and radiomics can help detect structural and microstructural abnormalities at an earlier stage before the development of degeneration. All the above-mentioned methods are being implemented into clinical practice and may allow diagnosing the disease sooner and monitor its development. Comparison of the currently used imaging techniques is shown in Table 2.

**Table 2. Comparison of Quantitative Imaging Modalities for Spine Assessment**

| Imaging Technique | Primary Target | Advantages | Limitations | Clinical Utility | Key Reference |
|---|---|---|---|---|---|
| Conventional Radiography | Alignment and bony structures | Widely available and cost-effective | Poor soft-tissue visualization | Initial assessment of degeneration | [14] |
| DXA | Bone mineral density | Gold standard for osteoporosis screening | Limited structural assessment | Fracture-risk evaluation | [15] |
| QCT | Trabecular and cortical bone | Volumetric bone analysis | Higher radiation dose | Vertebral bone quality assessment | [13] |
| MRI | Discs, nerves, muscles, marrow | Excellent soft-tissue contrast | Expensive and time-consuming | Comprehensive spinal evaluation | [16] |
| Diffusion Kurtosis Imaging | Tissue microstructure | Detects early degenerative changes | Limited availability | Early disease detection | [17] |
| Quantitative | Tissue | Objective | Requires | Monitoring | [18] |

| | | | | | |
|---|---|---|---|---|---|
| MRI | composition biomarkers | quantitative assessment | advanced protocols | disease progression | |
| Musculoskeletal Ultrasound | Soft tissues and muscles | Dynamic and non-invasive | Operator dependent | Functional physiotherapy assessment | [19] |
| Radiomics | Quantitative image features | Predictive and prognostic potential | Lack of standardization | Risk prediction and precision medicine | [20] |

### 3.3 Bone Quality Assessment and Osteoporosis-Related Spinal Degeneration

The concept of bone quality is significant in degenerative spine disorders. It is a critical factor that needs consideration because lower bone mineral density and microstructure impair the spine's ability to withstand vertebral compression fractures, vertebral deformation, pain, and poor functioning. Osteoporosis often accompanies degenerative spine diseases, especially among the elderly. However, the development of quantitative imaging techniques has made it possible to detect imaging biomarkers that indicate the risk of fractures and bone fragility in patients suffering from degenerative spine diseases. An analysis of bone quality enables healthcare specialists to determine risks and develop appropriate rehabilitation strategies. The most valuable vertebral bone quality biomarkers are provided in Table 3.

**Table 3. Imaging Biomarkers Associated with Vertebral Bone Quality**

| Biomarker | Imaging Method | Clinical Significance | Clinical Application | Key Reference |
|---|---|---|---|---|
| Bone Mineral Density | DXA | Osteoporosis diagnosis | Fracture-risk prediction | [15] |
| Trabecular Bone Density | QCT | Vertebral strength assessment | Surgical planning | [13] |
| Vertebral Marrow Alterations | MRI | Early degeneration detection | Disease monitoring | [13] |
| Endplate Defects | MRI | Marker of disc degeneration | Progression assessment | [11] |
| Modic Changes | MRI | Associated with chronic spinal pain | Prognostic evaluation | [11] |
| Paraspinal Muscle Fatty Infiltration | MRI | Indicator of muscle degeneration | Rehabilitation planning | [16] |
| Radiomic Features | CT/MRI | Quantitative disease characterization | Predictive modeling | [20] |

### 3.4 Functional Physiotherapy Assessment and Clinical Evaluation

Despite the useful information on the anatomy that imaging allows to receive, functional physiotherapy assessment is critical for the consideration of the impact of the spine deterioration on patients' everyday life. The assessment of patients' posture, flexibility, strength, core stability, balance, gait, and disability provides an understanding of the functional problems that patients face. Functional assessment helps to detect movement disorders, neuromuscular problems, and activity limitations that might not be revealed using imaging. Standardized tests including the Oswestry Disability Index, Roland-Morris Disability Questionnaire, Neck Disability Index, and several pain assessment tools are used to objectively assess patients' outcomes. With the inclusion of the functional assessment in clinical practice, rehabilitation can be tailored to each patient individually. Physiotherapy assessment methods and their use cases are presented in Table 4.

**Table 4. Functional Physiotherapy Assessment Tools and Clinical Applications**

| Assessment Domain | Tool/Method | Clinical Purpose | Outcome Measured | Key Reference |
|---|---|---|---|---|
| Postural Assessment | Postural alignment analysis | Detect biomechanical abnormalities | Postural deviations | [21] |
| Range of Motion | Goniometry/Inclinometry | Assess spinal mobility | Flexibility and stiffness | [22] |
| Functional Movement | Functional movement screening | Evaluate movement quality | Functional limitation | [23] |
| Muscle Strength | Dynamometry | Quantify muscular performance | Strength deficits | [24] |
| Core Stability | Trunk endurance tests | Assess spinal control | Stability capacity | [23] |
| Balance Assessment | Berg Balance Scale/TUG | Identify fall risk | Postural control | [25] |
| Gait Analysis | Instrumented gait assessment | Evaluate locomotor function | Walking performance | [26] |

| | | | | |
|---|---|---|---|---|
| Disability Assessment | Oswestry Disability Index | Assess low-back disability | Functional impairment | [27] |
| Neck Disability Assessment | Neck Disability Index | Assess cervical dysfunction | Functional status | [10] |
| Pain Assessment | VAS/NRS/McGill Questionnaire | Evaluate pain severity | Pain intensity and quality | [28] |

### 3.5 Relationship Between Imaging Findings, Pain, and Functional Impairment

The correlation between structural changes and clinical manifestations in degenerative spine diseases is sometimes complicated. Although some imaging features, such as vertebral fracture, spinal stenosis, and severe degenerative changes in muscles, can be highly correlated with pain and dysfunction, there are cases where patients have large amounts of anatomical alterations, but no signs or symptoms. At the same time, those people who have minor anatomical abnormalities can suffer from severe pain and dysfunction. Thus, the inconsistency between the imaging characteristics and symptoms proves the multifactorial character of these diseases, which means that biological, biomechanical, psychological, and behavioral factors affect their development. Key research papers on this issue are listed in Table 5.

**Table 5. Studies Examining Relationships Between Imaging Findings and Functional Outcomes**

| Imaging Finding | Functional Outcome | Main Observation | Clinical Interpretation | Key Reference |
|---|---|---|---|---|
| Disc Degeneration | Low back pain | Moderate association | Requires clinical correlation | [11] |
| Facet Arthropathy | Reduced mobility | Associated with stiffness and pain | Functional assessment required | [12] |
| Paraspinal Muscle Degeneration | Muscle weakness | Strong relationship with disability | Rehabilitation target | [16] |
| Vertebral Compression Fractures | Functional decline | Strong association with disability | Requires osteoporosis management | [13] |
| Modic Changes | Chronic pain | Variable relationship | Not always symptom-related | [11] |
| Spinal Stenosis | Walking impairment | Associated with reduced mobility | Influences treatment planning | [12] |
| Reduced Bone Density | Increased disability risk | Greater functional decline in elderly | Supports early intervention | [15] |

### 3.6 Emerging Technologies and Integrated Approaches for Early Detection and Management

The recent technological developments have revolutionized the diagnosis and management of degenerative conditions of the spine. Use of AI, machine learning, radiomics, wearables, inertial motion units, and tele-rehabilitation platforms have enhanced the ability to diagnose and monitor the progress of patients from afar. With the help of the new technologies, clinicians can now merge imaging data with physical performance to get a holistic picture of the disease and its progression. The blend of quantitative imaging, physical therapy, and digital health technologies has made precision medicine possible, wherein therapies are personalized based on the needs of the individual patient. The new technologies and their possible uses for spinal care are detailed in Table 6.

**Table 6. Emerging Technologies for Early Detection and Management of Degenerative Spine Disorders**

| Technology | Principle | Clinical Application | Future Potential | Key Reference |
|---|---|---|---|---|
| Artificial Intelligence | Automated image interpretation | Diagnostic support | Precision diagnosis | [29] |
| Machine Learning | Predictive analytics | Risk stratification | Personalized treatment planning | [30] |
| Radiomics | Quantitative image analysis | Biomarker discovery | Prognostic modeling | [20] |
| Wearable Sensors | Continuous movement monitoring | Functional assessment | Remote patient monitoring | [24] |
| Inertial Measurement Units (IMUs) | Motion tracking technology | Gait and posture analysis | Early screening and monitoring | [26] |
| Tele-Rehabilitation | Remote exercise delivery | Long-term management | Improved accessibility | [31] |
| Precision Spine Medicine | Integrated patient profiling | Personalized care pathways | Future clinical paradigm | [32] |

## 4. DISCUSSION

Findings from the study highlight the growing importance of the use of quantitative bone imaging in conjunction with functional physiotherapy assessment in the early detection and treatment of degenerative spine diseases. Degenerative spine disease is complex and has several factors involved in its occurrence such as deterioration of the structure, change in the bone quality, muscle dysfunctions, pain, and impaired function. Findings from the reviewed literature suggest that imaging can provide valuable data on vertebrae integrity, disc degeneration, and musculoskeletal tissues; however, they do not completely explain what happens in the clinical setting of the patient. In the same manner, functional physiotherapy assessment is essential in offering a critical information on mobility, strength, balance, and disability but might fail to offer a sufficient information on the underlying structural abnormality. Therefore, an integrated approach that incorporates these complementary methods provides a more in-depth picture of the disease condition and can contribute to the earlier diagnosis, better risk identification, and more personalized rehabilitation.

The current results align with other studies that have underscored the importance of the holistic musculoskeletal assessment systems. A professional opinion on the evaluation of musculoskeletal disease in the early years of life revealed the significance of integrating several diagnostic methods to enhance the detection of disease-related alterations before the emergence of the subsequent clinical symptoms [33]. In the same manner, a proposed framework of integrated clinical evaluation of patients with shoulder pain revealed that the combination of the structural, functional, and patient-centered assessment can improve clinical decision-making and progress in treatment [34]. Interdisciplinary options have also been suggested in the management of temporomandibular joint osteoarthritis where structural imaging results are observed and interpreted with functional and clinical assessment to enhance patient care [35]. Moreover, data on the benefits of physiotherapy treatments in the management of temporomandibular dysfunction has also revealed the strong association that exists between structural abnormalities and functional impairments, which has also supported the significance of multidimensional assessment strategies [36]. This review also indicates agreement with the concerns of overutilizing imaging as a single modality because inappropriate imaging can lead to higher health care expenditures and unwanted downstream effects without a likely subsequent positive impact on patient outcomes [37]. Moreover, recent studies in physiotherapy also stress the need to incorporate functional, behavioral, and psychosocial variables with structural pathology in the management of chronic musculoskeletal disorders, which is why the combination of the two suggested in the current review is important [38].

Clinically, quantitative imaging and physiotherapy assessment can enhance patient management by ensuring more accurate diagnosis and intervention strategies. The prevention of long-term disability can be assisted by the early detection of vertebral fragility, muscle degeneration, balance and movement dysfunction and moderate the outcome of rehabilitation. This type of strategy is especially applicable to the aging demographics, where osteoporosis and degeneration of the spine are commonly comorbid conditions, which cause significant healthcare costs. The use of new technologies, such as artificial intelligence, radiomics, wearables, and digital rehabilitation solutions, can also help increase the accuracy of the diagnosis and improve the monitoring opportunities.

Although such positive results are promising, there are a number of limitations that should be noted. A large proportion of the existing evidence is still heterogeneous in terms of imaging protocols, functional and outcome measures therefore precluding a direct comparison across studies. Furthermore, most of the new technologies are still at an initial phase of clinical validation and their daily use in practice applicability may be limited by financial factors, their availability and technical skills. The qualitative nature of the review might be a further limitation to the quantitative assessment of the strength of individual associations presented in the literature.

The next phase of research should be aimed at creating standardized assessment protocols that will combine imaging biomarkers with functional physiotherapy outcomes. To ascertain the predictive quality of combined diagnostic methods on disease development, treatment responsiveness, and functional outcomes in the long run, large-scale longitudinal research is required. Additional research on the use of artificial intelligence-based diagnostics, digital health technologies, and precision rehabilitation models can also aid in more personal and effective management of people with degenerative spine disorders.

## 5. CONCLUSION

Particularly in older adults, degenerative diseases of the spine are important causes of chronic pain, disability, and low quality of life. It is important that an integrative diagnostic approach is applied, which involves quantitative imaging of bones together with physical therapy assessment of functions, to achieve better outcomes. As seen from the results of the review, modern imaging methods such as DXA, QCT, MRI, quantitative MRI, as well as radiomics, yield useful data about bone structure of the vertebrae and muscle structure. Nevertheless, imaging results alone are not enough to interpret the level of pain and functional limitations of patients. One of the conclusions made through this literature review is that functional physiotherapy evaluations, such as assessments of postural issues, movement, muscle strength, balance, walking ability, pain, and disability, contribute significantly to providing crucial additional information to clinical interpretations of imaging tests. Another point indicated by the reviewed studies is that combining structural and functional tests might improve diagnostics, help to stratify patients at risk, plan personalized rehabilitation strategies, and increase effectiveness in monitoring disease development and treatment. Moreover, this study stresses the growing number of opportunities provided by the novel technologies that include artificial intelligence, machine learning, wearables, and tele-rehabilitation systems in the context of precision spine care. Overall, the multidisciplinary and patient-centered approach based on both imaging techniques and functional physiotherapy may be taken into account when diagnosing, rehabilitating, and managing spine degenerations.

**REFERENCES**


1. Kumar R, Marla K, Sporn K, Paladugu P, Khanna A, Gowda C, Ngo A, Waisberg E, Jagadeesan R, Tavakkoli A. Emerging Diagnostic Approaches for Musculoskeletal Disorders: Advances in Imaging, Biomarkers, and Clinical Assessment. Diagnostics. 2025 Jun 27;15(13):1648.
2. Rutnagur J, Frost A, Arora M, Lowrie J, Baliga S. Acute spinal problems in the elderly. British Journal of Hospital Medicine. 2025 Apr 25;86(4):1-6.
3. AGARWAL Y, JAIN C, BHAYANA A. Diagnostic Imaging and Radiology for Physical Therapists. Tidy's Physiotherapy, South Asia edition-E-Book. 2024 Dec 18:208.
4. Finucane LM, Downie A, Mercer C, Greenhalgh SM, Boissonnault WG, Pool-Goudzwaard AL, Beneciuk JM, Leech RL, Selfe J. International framework for red flags for potential serious spinal pathologies. journal of orthopaedic & sports physical therapy. 2020 Jul;50(7):350-72.
5. Pradat PF, Bernard E, Corcia P, Couratier P, Jublanc C, Querin G, Morélot Panzini C, Salachas F, Vial C, Wahbi K, Bede P. The French national protocol for Kennedy's disease (SBMA): consensus diagnostic and management recommendations. Orphanet Journal of Rare Diseases. 2020 Apr 10;15(1):90.
6. Kuang H, Chen L, Huang M, Chen J. Management of adolescent scoliosis: a comprehensive review of etiology and rehabilitation. Frontiers in Pediatrics. 2025 Jul 16;13:1596400.
7. Das S, Ramteke H. A comprehensive review of the role of biomarkers in early diagnosis of Parkinson's disease. Cureus. 2024 Feb 16;16(2).
8. Tavakoli J, Hu Q, Tipper JL, Tang Y. Aggregation-induced emission biomarkers for early detection of orthopaedic implant failure. Aggregate. 2024 Dec;5(6):e645.
9. Ma Z, Ye Q, Du W, Wang J, Feng H, Zhang Y. Patients' knowledge, attitude, and practice toward degenerative lumbar spine disease: A cross-sectional study in Shanxi, China. Scientific Reports. 2025 Jul 1;15(1):20648.
10. Cervellini M, Feller D, Maselli F, Rossettini G, Cook C, Tabrah J, Chauhan RV, Taylor A, Kerry R, Young I, Dunning J. Understanding degenerative cervical myelopathy in musculoskeletal practice. Journal of Manual & Manipulative Therapy. 2025 May 4;33(3):207-23.
11. Fujii K, Yamazaki M, Kang JD, Risbud MV, Cho SK, Qureshi SA, Hecht AC, Iatridis JC. Discogenic back pain: literature review of definition, diagnosis, and treatment. Journal of Bone and Mineral Research Plus. 2019 May 1;3(5):e10180.
12. Huang X, Cai Y, Chen K, Ren Q, Huang B, Wan G, Wang Y, Lin J, Zhao J. Risk factors and treatment strategies for adjacent segment disease following spinal fusion. Molecular Medicine Reports. 2024 Nov 18;31(2):33.
13. Din RU, Yang H. Emerging MRI-based spine scoring techniques targeting bone quality to assess osteoporosis, vertebral fracture risk, other spinal degenerative diseases, and post-surgical outcomes. La radiologia medica. 2025 Sep;130(9):1442-59.
14. Oakley PA, Haas JW, Harrison DE. The rationale and safety of routine imaging in rehabilitative spine care: delayed radiographs for patients presenting with spine disorders is debatable. Dose-Response. 2025 Aug 28;23(3):15593258251374411.
15. Perrone S, Caporilli C, Grassi F, Ferrocino M, Biagi E, Dell'Orto V, Beretta V, Petrolini C, Gambini L, Street ME, Dall'Asta A. Prenatal and neonatal bone health: updated review on early identification of newborns at high risk for osteopenia. Nutrients. 2023 Aug 9;15(16):3515.
16. Li X, Dong F, Chen X, Luo X, Wang W. Radiological frontiers in understanding paraspinal muscle pathophysiology in chronic low back pain. Frontiers in Medicine. 2025 Sep 23;12:1653876.
17. Barnes NA, Dkhar W, Kadavigere R, Sukumar S, Pradhan A, PS P. Exploring mean kurtosis in MR diffusion kurtosis imaging for early detection of lumbar spine degeneration: a systematic review. F1000Research. 2025 Sep 1;14:440.
18. McKay MJ, Weber KA, Wesselink EO, Smith ZA, Abbott R, Anderson DB, Ashton-James CE, Atyeo J, Beach AJ, Burns J, Clarke S. MuscleMap: An Open-Source, Community-Supported Consortium for Whole-Body Quantitative MRI of Muscle. Journal of imaging. 2024 Oct 22;10(11):262.
19. Papadopoulos E, Mani R. The value of musculoskeletal ultrasound imaging in physiotherapy clinical assessment and practice. Health & Research Journal. 2025 Jul 7;11(3):282-96.
20. Angelone F, Ciliberti FK, Tobia GP, Jónsson Jr H, Ponsiglione AM, Gislason MK, Tortorella F, Amato F, Gargiulo P. Innovative diagnostic approaches for predicting knee cartilage degeneration in osteoarthritis patients: A radiomics-based study. Information Systems Frontiers. 2025 Feb;27(1):51-73.
21. Alrowili AN, Alanazi KH, Aldowihi RJ, Alsharari SM, Alrajraji HS, Alkuwaykibi SH, Alruwily MA, Alrowili DN, Alrowily AK, Shajiri MM. Physiotherapy for postural disorders: a comprehensive review of treatment modalities. Journal of International Crisis and Risk Communication Research. 2024;7(S9):367.
22. Sadineni HS. Orthopedic Applications: Advancing Physiotherapy in. Physical Therapy: Towards Evidence-Based Practice. 2024 Feb 28:157.
23. O'Sullivan PB, Caneiro JP, O'Keeffe M, Smith A, Dankaerts W, Fersum K, O'Sullivan K. Cognitive functional therapy: an integrated behavioral approach for the targeted management of disabling low back pain. Physical therapy. 2018 May;98(5):408-23.
24. Varrassi G, Leoni ML, Al-Alwany AA, Sarzi Puttini P, Farì G. Bioengineering support in the assessment and rehabilitation of low back pain. Bioengineering. 2025 Aug 22;12(9):900.
25. Wang J, Li Y, Yang GY, Jin K. Age-related dysfunction in balance: a comprehensive review of causes, consequences, and interventions. Aging and disease. 2024 Jan 24;16(2):714.

26. Pelc M, Vilimkova Kahankova R, Blaszczyszyn M, Mikolajewski D, Konieczny M, Khoma V, Bara G, Zygarlicki J, Martinek R, Gupta MK, Gorzelanczyk EJ. Initial study on an expert system for spine diseases screening using inertial measurement unit. Scientific Reports. 2023 Jun 27;13(1):10440.
27. Foster NE, Anema JR, Cherkin D, Chou R, Cohen SP, Gross DP, Ferreira PH, Fritz JM, Koes BW, Peul W, Turner JA. Prevention and treatment of low back pain: evidence, challenges, and promising directions. The Lancet. 2018 Jun 9;391(10137):2368-83.
28. Varrassi G, Farì G, Narvaez Tamayo MA, Gomez MP, Guerrero Liñeiro AM, Pereira CL, Samy Aziz E, Gharibo C, Kaye AD, Garcia-Larrea L, Moka E. Mixed pain: clinical practice recommendations. Frontiers in Medicine. 2025 Oct 9;12:1659490.
29. Jawed AM, Zhang L, Zhang Z, Liu Q, Ahmed W, Wang H. Artificial intelligence and machine learning in spine care: Advancing precision diagnosis, treatment, and rehabilitation. World Journal of Orthopedics. 2025 Aug 18;16(8):107064.
30. Yagi M, Yamanouchi K, Fujita N, Funao H, Ebata S. Revolutionizing spinal care: Current applications and future directions of artificial intelligence and machine learning. Journal of Clinical Medicine. 2023 Jun 21;12(13):4188.
31. Weise H, Zenner B, Schmiedchen B, Benning L, Bulitta M, Schmitz D, Weise K. The effect of an app-based home exercise program on self-reported pain intensity in unspecific and degenerative back pain: pragmatic open-label randomized controlled trial. Journal of medical Internet research. 2022 Oct 28;24(10):e41899.
32. Trento A, Rapisarda S, Bresolin N, Valenti A, Giordan E. Artificial intelligence and its impact on the management of lumbar degenerative pathology: a narrative review. Medicina. 2025 Aug 1;61(8):1400.
33. Seuser A, Khayat CD, Negrier C, Sabbour A, Heijnen L. Evaluation of early musculoskeletal disease in patients with haemophilia: results from an expert consensus. Blood Coagulation & Fibrinolysis. 2018 Sep 1;29(6):509-20.
34. Ristori D, Miele S, Rossettini G, Monaldi E, Arceri D, Testa M. Towards an integrated clinical framework for patient with shoulder pain. Archives of physiotherapy. 2018 May 30;8(1):7.
35. Derwich M, Mitus-Kenig M, Pawlowska E. Interdisciplinary approach to the temporomandibular joint osteoarthritis—review of the literature. Medicina. 2020 May 9;56(5):225.
36. Crăciun MD, Geman O, Leuciuc FV, Holubiac IŞ, Gheorghiţă D, Filip F. Effectiveness of physiotherapy in the treatment of temporomandibular joint dysfunction and the relationship with cervical spine. Biomedicines. 2022 Nov 17;10(11):2962.
37. Sajid IM, Parkunan A, Frost K. Unintended consequences: quantifying the benefits, iatrogenic harms and downstream cascade costs of musculoskeletal MRI in UK primary care. BMJ open quality. 2021 Jul 2;10(3).
38. Teo PL, Bennell KL, Lawford BJ, Egerton T, Dziedzic KS, Hinman RS. Physiotherapists may improve management of knee osteoarthritis through greater psychosocial focus, being proactive with advice, and offering longer-term reviews: a qualitative study. Journal of Physiotherapy. 2020 Oct 1;66(4):256-65.