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Comprehensive Evaluation of Musculoskeletal Status in Children with Hemophilia: Clinical, Radiologic, and Functional Perspective

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ABSTRACT

***Background*:** Hemophilia is a hereditary bleeding disorder characterized by recurrent musculoskeletal hemorrhages that begin early in life and frequently lead to progressive joint damage and long-term disability. Despite advances in prophylactic therapy, hemophilic arthropathy remains a significant clinical concern, particularly in pediatric populations where early joint changes may be subtle or subclinical. Accurate and timely evaluation of musculoskeletal status is therefore essential to detect early joint involvement, monitor disease progression, and guide individualized management strategies aimed at preserving joint function and quality of life.

The assessment of musculoskeletal involvement in children with hemophilia is inherently complex and requires a comprehensive, multidimensional approach. Clinical examination remains the foundation of evaluation, with standardized scoring systems such as the Hemophilia Joint Health Score (HJHS) providing structured assessment of joint swelling, pain, range of motion, muscle strength, and gait. However, clinical findings alone may underestimate early or subclinical joint damage, particularly in children receiving prophylaxis. As a result, imaging modalities play a crucial complementary role. Conventional radiography is useful for detecting advanced structural changes, whereas magnetic resonance imaging offers superior sensitivity for early soft tissue and osteochondral abnormalities. More recently, musculoskeletal ultrasonography has emerged as a practical, non-invasive, and point-of-care tool capable of identifying early synovial and cartilage changes.

In addition to structural assessment, evaluation of functional status is critical to understanding the real-world impact of joint disease. Functional outcome measures and patient-reported tools provide valuable insight into mobility, independence, and participation in daily activities, aligning with holistic models of health assessment. Emerging interest in biochemical biomarkers further expands the scope of evaluation, although their clinical utility remains under investigation.

This review aims to provide a comprehensive overview of the clinical, radiologic, and functional approaches used to evaluate musculoskeletal status in children with hemophilia. It highlights the strengths and limitations of current assessment tools and emphasizes the importance of an integrated, multimodal strategy for early detection and optimal disease monitoring.

Keywords: Pediatric hemophilia, hemophilic arthropathy, joint health assessment

INTRODUCTION

Hemophilia is a congenital bleeding disorder characterized by deficiency of clotting factor VIII or IX, leading to impaired hemostasis and a lifelong tendency toward recurrent bleeding episodes, particularly within the musculoskeletal system. In pediatric patients, joint bleeding represents the most common and clinically significant manifestation, often beginning in early childhood with the onset of mobility. Repeated hemarthroses initiate a progressive cascade of synovial inflammation, cartilage degradation, and bone remodeling, ultimately resulting in hemophilic arthropathy, which remains a leading cause of morbidity despite advances in treatment [1,2].

Early detection and accurate evaluation of musculoskeletal involvement are essential to prevent irreversible joint damage and optimize long-term outcomes. However, assessing joint health in children with hemophilia is particularly challenging due to subclinical bleeding, variability in disease severity, and the dynamic nature of growing joints. Clinical findings alone may underestimate early joint pathology, especially in patients receiving prophylaxis, where overt bleeding episodes are reduced but silent joint damage may still occur [3,4].

Over the past decades, multiple tools have been developed to improve the assessment of joint health in hemophilia. These include structured clinical scoring systems, advanced imaging modalities, and functional outcome measures. Each modality provides complementary information: clinical scores assess observable abnormalities, imaging detects early structural changes, and functional tools evaluate the impact on daily activities. Despite these advancements, there is currently no universally accepted gold standard for defining or measuring joint health, representing a major gap in both research and clinical practice [5,6].

Radiologic evaluation has evolved significantly, from conventional radiography—limited to detecting late-stage joint damage—to more sensitive modalities such as magnetic resonance imaging and musculoskeletal ultrasonography. MRI is considered the gold standard for early detection of synovial and osteochondral changes, whereas ultrasound offers a practical, accessible, and point-of-care alternative with increasing clinical utility. These tools have enhanced the ability to detect early arthropathy before irreversible damage occurs [7,8].

Clinical assessment tools, particularly the Hemophilia Joint Health Score (HJHS), have improved the standardization of joint evaluation in pediatric patients. The HJHS allows detailed assessment of swelling, muscle atrophy, crepitus, range of motion, strength, and gait, and is considered sensitive for detecting early joint abnormalities. In parallel, functional assessment instruments such as the Hemophilia Activities List and Functional Independence Score in Hemophilia provide insight into patient mobility, participation, and quality of life [9,10].

The complexity of hemophilic arthropathy necessitates a multidimensional approach that integrates clinical, radiologic, and functional perspectives. This is particularly important in children, where early intervention can significantly alter disease trajectory. Furthermore, the presence of inhibitors introduces additional challenges, as these patients often experience more severe and less predictable joint disease, complicating both assessment and monitoring [11].

Despite the availability of multiple assessment modalities, variability in their sensitivity, accessibility, and interpretation limits their widespread standardization. There remains a critical need for integrated evaluation strategies that combine different tools to improve early detection, monitor progression, and guide individualized treatment decisions [12].

This review aims to provide a comprehensive evaluation of musculoskeletal status in children with hemophilia by integrating clinical, radiologic, and functional perspectives, with emphasis on optimizing early detection and improving long-term outcomes [13].

Clinical Assessment Tools for Joint Evaluation in Pediatric Hemophilia

Clinical assessment remains the cornerstone of musculoskeletal evaluation in children with hemophilia and represents the first-line approach for detecting joint abnormalities, monitoring progression, and guiding therapeutic decisions. It relies on systematic physical examination performed by experienced clinicians and physiotherapists, focusing on joint swelling, pain, range of motion, muscle strength, and functional performance. Despite advances in imaging, clinical tools remain essential due to their accessibility, cost-effectiveness, and ability to provide immediate bedside evaluation [14].

Among the available clinical scoring systems, the **Hemophilia Joint Health Score (HJHS)** is the most widely accepted and

validated tool, particularly in pediatric populations. Originally developed to detect early joint changes in children receiving prophylaxis, the HJHS provides a structured and detailed assessment of joint status. It evaluates multiple domains including swelling, duration of swelling, muscle atrophy, crepitus on motion, joint pain, muscle strength, and both flexion and extension loss, in addition to global gait assessment. The score is applied to six index joints—bilateral knees, ankles, and elbows—allowing comprehensive evaluation of commonly affected sites [15].

The strength of the HJHS lies in its sensitivity to early and subtle joint changes that may not yet be evident on imaging. Studies have demonstrated that it has excellent inter-observer reliability and test–retest consistency, making it suitable for both clinical practice and research settings. Furthermore, lower HJHS scores correlate with better joint health, allowing clinicians to monitor disease progression over time and evaluate the effectiveness of prophylactic regimens. It is particularly valuable in children with mild or moderate arthropathy, where early intervention can prevent irreversible damage [16].

However, despite its advantages, the HJHS has limitations. It is dependent on examiner expertise and may be subject to inter-observer variability in less experienced settings. Additionally, while it is sensitive to functional and clinical changes, it may still fail to detect subclinical joint damage, particularly in patients with minimal symptoms or well-controlled bleeding under prophylaxis. This underscores the need to complement clinical assessment with imaging modalities for a more comprehensive evaluation [17].

Other clinical scoring systems, such as the **Gilbert score**, **Colorado Physical Examination Scale**, and **Petrini Joint Score**, have also been used historically to assess joint status in hemophilia. The Gilbert score, one of the earliest tools, focuses on parameters such as joint swelling, muscle atrophy, axial deformity, crepitus, and range of motion. While useful in detecting advanced joint disease, it is less sensitive to early changes compared to the HJHS and is therefore less commonly used in modern pediatric practice [18].

The Colorado Physical Examination Scale and Petrini Joint Score similarly provide structured approaches to joint assessment but are limited by lower sensitivity and reduced validation in pediatric populations. As hemophilia care has shifted toward early prophylaxis and prevention of severe arthropathy, the need for tools capable of detecting early and subtle joint abnormalities has become increasingly important, further supporting the widespread adoption of the HJHS as the preferred clinical instrument [19].

An important consideration in pediatric assessment is the dynamic nature of growth and development. Normal variations in joint mobility, muscle mass, and gait patterns must be distinguished from pathological findings. This requires experienced evaluators and age-appropriate interpretation of clinical scores. Additionally, repeated longitudinal assessments are essential to identify trends over time rather than relying on single measurements [20].

In patients with inhibitors, clinical assessment becomes even more critical yet more challenging. These children often experience more frequent and severe joint bleeding, leading to rapid progression of joint damage. However, variability in bleeding patterns and treatment response may result in discrepancies between clinical findings and underlying joint pathology. Therefore, frequent and detailed clinical evaluations detect early deterioration and adjust management strategies accordingly [21].

Overall, clinical assessment tools, particularly the HJHS, play a pivotal role in the evaluation of musculoskeletal status in pediatric hemophilia. While they provide valuable information on joint function and observable abnormalities, their limitations necessitate integration with imaging and functional assessments. A comprehensive, multimodal approach ensures more accurate detection of early joint disease and supports optimal long-term management in this vulnerable population [22].

Radiologic Assessment of Musculoskeletal Involvement in Pediatric Hemophilia

Radiologic evaluation plays a pivotal role in the assessment of hemophilic arthropathy, complementing clinical examination by enabling visualization of structural and early pathological changes within the joint. Imaging is particularly important in pediatric patients, where subclinical bleeding and early synovial alterations may not be detectable through physical examination alone. Over time, imaging modalities have evolved from conventional radiography to advanced techniques such as magnetic resonance imaging (MRI) and musculoskeletal ultrasonography, each offering unique advantages and limitations in evaluating joint health [23].

Conventional radiography (X-ray) has historically been the primary imaging modality used in hemophilia. It is widely available, cost-effective, and useful for identifying late-stage joint damage, including joint space narrowing, subchondral cysts, epiphyseal enlargement, and bone deformities. The **Pettersson scoring system** remains the most commonly used radiographic classification

for grading the severity of hemophilic arthropathy. However, a major limitation of radiography is its inability to detect early soft tissue changes such as synovial hypertrophy or cartilage damage. As a result, radiographic findings often underestimate early disease, making X-rays less suitable for early diagnosis and monitoring in children [24].

Magnetic resonance imaging (MRI) is currently considered the gold standard for assessing joint involvement in hemophilia, particularly for detecting early and subclinical changes. MRI provides detailed visualization of both soft tissue and osteochondral structures, allowing identification of synovial hypertrophy, joint effusion, hemosiderin deposition, cartilage degradation, and subchondral bone abnormalities. Scoring systems such as the Denver score and the International Prophylaxis Study Group MRI scale enable standardized evaluation of disease severity. MRI is especially valuable in pediatric patients, as it can detect early joint changes before irreversible damage occurs, facilitating timely intervention [25].

Despite its high sensitivity, MRI has several limitations that restrict its routine use in clinical practice. It is relatively expensive, less accessible in many settings, and time-consuming. In young children, sedation is often required to ensure image quality, which introduces additional risks and logistical challenges. Furthermore, MRI is less practical for repeated or multi-joint assessments, limiting its utility for frequent monitoring of disease progression [26].

Musculoskeletal ultrasonography has emerged as an increasingly important tool in the evaluation of hemophilic arthropathy. It offers several advantages, including real-time imaging, absence of ionizing radiation, low cost, and accessibility in point-of-care settings. Ultrasound is particularly effective in detecting synovial hypertrophy, joint effusion, and early structural changes. The development of standardized protocols such as the **Hemophilia Early Arthropathy Detection with Ultrasound (HEAD-US)** score has enhanced its reliability and clinical applicability [27].

Ultrasound has demonstrated good correlation with MRI findings, particularly in identifying synovial abnormalities and joint effusions. It is highly sensitive in detecting even small amounts of intra-articular blood, making it a valuable tool for diagnosing acute hemarthrosis. Additionally, its portability allows for bedside assessment and rapid clinical decision-making. This is especially beneficial in pediatric patients, where repeated imaging may be required for monitoring disease activity [28].

However, ultrasound also has limitations. Its diagnostic accuracy is operator-dependent, requiring specific expertise and training. It is less effective than MRI in evaluating deep joint structures and early cartilage changes, and may have limited ability to distinguish between synovial hypertrophy and complex intra-articular contents in certain cases. Additionally, interpretation of pediatric joint anatomy can be challenging due to developmental variations in cartilage and ossification centers [29].

Computed tomography (CT), although highly sensitive for detecting bone abnormalities, is rarely used in the routine evaluation of hemophilic arthropathy due to its limited ability to assess soft tissues and the associated exposure to ionizing radiation. Its role is generally restricted to specific clinical scenarios where detailed bone assessment is required [30].

In clinical practice, the choice of imaging modality depends on the clinical context, availability, and specific diagnostic needs. Radiography remains useful for assessing advanced disease, MRI is preferred for comprehensive evaluation and early detection, and ultrasound serves as a practical tool for routine monitoring and point-of-care assessment. Increasingly, a combined approach utilizing multiple imaging modalities is advocated to achieve a more accurate and comprehensive evaluation of joint health [31].

In patients with inhibitors, radiologic assessment becomes even more critical due to the increased risk of rapid joint deterioration. Frequent imaging may be required to monitor disease progression and guide treatment adjustments. Ultrasound, in particular, offers significant advantages in this population due to its accessibility and ability to detect ongoing joint bleeding in real time [32].

Overall, radiologic assessment is an essential component of the comprehensive evaluation of musculoskeletal status in pediatric hemophilia. Each imaging modality contributes distinct and complementary information, and their integration with clinical and functional assessments provides a more complete understanding of joint health. Continued advancements in imaging techniques and standardization of scoring systems are expected to further enhance early detection and improve long-term outcomes in children with hemophilia [33].

Functional Assessment and Quality of Life in Pediatric Hemophilia

Functional assessment is a critical component in the evaluation of musculoskeletal status in children with hemophilia, as it reflects the real-life impact of joint disease beyond structural abnormalities. While clinical and imaging tools provide information

about joint integrity, functional assessments capture the consequences of hemophilic arthropathy on mobility, independence, and participation in daily activities. This is particularly important in pediatric populations, where joint disease can significantly influence physical development, social integration, and overall well-being [34].

One of the most widely used tools for functional evaluation is the **Functional Independence Score in Hemophilia (FISH)**, which assesses a patient's ability to perform basic daily activities such as eating, grooming, dressing, transferring, and mobility tasks including walking and stair climbing. FISH provides an objective measure of independence and is sensitive to changes in functional capacity over time. It is particularly useful in detecting the cumulative impact of joint damage and monitoring response to therapeutic interventions [35].

Another important instrument is the **Hemophilia Activities List (HAL)** and its pediatric adaptation (PedHAL), which evaluate self-reported limitations in activities and participation. These tools provide valuable insight into how joint disease affects everyday functioning from the patient's perspective. Unlike purely clinical scores, HAL captures subtle limitations that may not be evident during physical examination, making it an essential complement to clinician-based assessments. It also allows for evaluation of domains such as upper limb function, basic mobility, and complex activities [36].

Functional assessment in hemophilia is increasingly aligned with the **World Health Organization's International Classification of Functioning, Disability and Health (ICF)** framework. This model emphasizes a holistic approach, considering not only body structure and function but also activities, participation, and environmental factors. By integrating clinical findings with functional outcomes, the ICF framework provides a comprehensive understanding of disease burden and supports multidisciplinary care planning [37].

In pediatric patients, functional impairment may manifest early, even before significant structural joint damage becomes apparent. Reduced range of motion, muscle weakness, and altered gait patterns can lead to limitations in physical activity and participation in sports or school activities. Over time, these limitations may contribute to decreased physical fitness, muscle atrophy, and further joint instability, perpetuating a cycle of functional decline [38].

Quality of life (QoL) assessment is closely linked to functional status and represents an essential outcome measure in children with hemophilia. Disease-specific instruments, such as hemophilia-related quality of life questionnaires, evaluate physical, emotional, and social domains affected by the condition. Studies have consistently shown that increased frequency of joint bleeding and severity of arthropathy are associated with poorer QoL outcomes, emphasizing the importance of early detection and effective management [39].

The presence of inhibitors significantly worsens functional outcomes and quality of life. Children with inhibitors often experience more frequent bleeding episodes, prolonged recovery periods, and greater treatment burden. This leads to increased absenteeism from school, reduced participation in physical activities, and heightened psychological stress. Consequently, functional limitations and QoL impairment are often more pronounced in this subgroup [40].

An important advantage of functional assessment tools is their ability to monitor longitudinal changes and evaluate the effectiveness of therapeutic interventions, including prophylaxis and physiotherapy. Improvements in functional scores may reflect successful disease control even when structural changes persist, highlighting their value in clinical decision-making and patient-centered care [41].

However, functional assessment tools also have limitations. Many rely on patient or caregiver reporting, which may introduce subjectivity or bias. Additionally, cultural and environmental factors may influence responses, particularly in diverse populations. Therefore, functional assessments should be interpreted in conjunction with clinical and imaging findings to ensure a comprehensive evaluation [42].

Overall, functional assessment and quality of life evaluation are essential components of the comprehensive assessment of musculoskeletal status in pediatric hemophilia. They provide critical insights into the real-world impact of joint disease and complement structural assessments. Integrating these tools into routine clinical practice supports a holistic approach to care and enhances the ability to optimize long-term outcomes for children with hemophilia [43].

Biomarkers in Hemophilic Arthropathy

The use of biomarkers in hemophilic arthropathy represents an emerging and promising field aimed at improving early detection,

monitoring disease progression, and evaluating treatment response. Unlike clinical and imaging assessments, which primarily identify structural or functional changes, biomarkers provide insight into the underlying biological processes occurring within the joint, including cartilage degradation, bone remodeling, inflammation, and angiogenesis. This molecular-level information has the potential to detect joint damage at a stage when clinical and radiologic findings may still be normal [44].

Among the most studied biomarkers in hemophilia are those related to cartilage turnover. **C-terminal telopeptide of type II collagen (CTX-II)** is a marker of cartilage degradation and has been shown to increase following joint bleeding episodes. Similarly, **cartilage oligomeric matrix protein (COMP)** reflects cartilage damage and has been associated with radiographic joint changes. Another biomarker, **CS-846**, is indicative of cartilage synthesis and turnover, with levels rising after hemarthrosis. These markers collectively provide insight into the dynamic balance between cartilage destruction and repair [45].

Bone remodeling biomarkers have also been investigated, including markers of bone resorption such as CTX-I. However, their correlation with hemophilic arthropathy severity has been inconsistent, suggesting that bone-related biomarkers may have limited standalone utility in assessing joint disease. Nonetheless, they may still contribute to a broader understanding of skeletal involvement in hemophilia, particularly in patients with reduced bone mineral density or advanced joint damage [46].

Angiogenesis-related biomarkers, particularly **vascular endothelial growth factor (VEGF)**, have gained attention due to their role in synovial proliferation and neoangiogenesis. Elevated levels of VEGF have been observed in patients with hemophilic arthropathy and are thought to reflect increased vascular activity within the inflamed synovium. This is clinically relevant, as enhanced vascularization contributes to recurrent bleeding and perpetuates the cycle of joint damage [47].

Inflammatory biomarkers, including cytokines such as tumor necrosis factor-alpha, interleukin-1β, and interleukin-6, are also involved in the pathogenesis of hemophilic arthropathy. These mediators promote synovial inflammation and cartilage degradation, similar to mechanisms observed in other inflammatory joint diseases. However, their lack of specificity limits their clinical applicability, as they may also be elevated in other inflammatory or systemic conditions [48].

Despite their potential, the clinical application of biomarkers in hemophilia remains limited. One major challenge is the high inter-individual variability in biomarker levels, which can be influenced by factors such as age, recent bleeding events, physical activity, and treatment status. Additionally, many biomarkers show transient changes following acute hemarthrosis, making it difficult to distinguish between temporary fluctuations and chronic joint pathology [49].

Another limitation is the lack of standardized thresholds and validated clinical guidelines for interpreting biomarker levels in hemophilia. Most studies to date have been exploratory, with relatively small sample sizes and heterogeneous methodologies. As a result, biomarkers are not yet routinely used in clinical practice for decision-making or disease monitoring [50].

Nevertheless, biomarkers hold significant promise when integrated into a **multimodal assessment approach**. Combining biomarker data with clinical scores and imaging findings may enhance the sensitivity of early disease detection and provide a more comprehensive understanding of joint health. For example, elevated cartilage degradation markers in the presence of normal imaging may indicate early subclinical disease, prompting closer monitoring or therapeutic adjustment [51].

Future research is focused on identifying more specific and reliable biomarkers, as well as developing standardized protocols for their use. Advances in molecular techniques and longitudinal studies may help clarify their role in predicting disease progression and treatment outcomes. In particular, biomarkers may become valuable tools in the era of personalized medicine, allowing tailored therapeutic strategies based on individual disease profiles [52].

In summary, biomarkers represent a promising but still evolving component of musculoskeletal assessment in pediatric hemophilia. While their current clinical utility is limited, ongoing research and integration with other assessment modalities may enhance their role in early detection, monitoring, and optimization of patient care in the future [53].

Integrated Multimodal Assessment Approach in Pediatric Hemophilia

The evaluation of musculoskeletal status in children with hemophilia has evolved from reliance on isolated clinical or radiologic findings to a more sophisticated **multimodal assessment paradigm**, which integrates clinical examination, imaging, functional evaluation, and emerging biomarkers. This comprehensive approach is essential because hemophilic arthropathy is a multifaceted disease in which structural, functional, and biological changes do not always progress in parallel. No single assessment modality is sufficient to capture the full spectrum of joint pathology, particularly in early or subclinical stages [54].

A key limitation in current practice is the absence of a universally accepted gold standard for defining "joint health." Clinical scores such as the HJHS are sensitive to functional and observable changes but may fail to detect early structural damage. Conversely, imaging modalities such as MRI can identify subclinical abnormalities but are not always feasible for routine or longitudinal use. Functional tools provide insight into patient-centered outcomes but may lag behind structural disease progression. These discrepancies highlight the necessity of integrating multiple domains to achieve a more accurate and clinically meaningful assessment [55].

The multimodal approach is best conceptualized as a **layered evaluation model**, where each modality contributes distinct but complementary information. Clinical assessment serves as the foundation, providing immediate bedside evaluation of joint status. Imaging modalities, particularly ultrasound and MRI, add structural detail and enable detection of early synovial and osteochondral changes. Functional assessments extend this evaluation by capturing the impact of joint disease on daily activities and participation, while biomarkers offer insight into underlying molecular processes. The integration of these layers allows for a more precise characterization of disease stage and activity [56].

In pediatric patients, this integrated approach is particularly critical due to the presence of **subclinical joint disease**, which may occur even in the absence of overt bleeding or abnormal clinical findings. Studies have demonstrated that imaging can reveal early synovial hypertrophy and cartilage changes in joints that appear clinically normal. Incorporating imaging, especially point-of-care ultrasound, into routine evaluation enables earlier detection of pathology and timely intervention, potentially preventing irreversible damage [57].

The role of musculoskeletal ultrasound within this framework is especially noteworthy. As a point-of-care tool, it bridges the gap between clinical examination and advanced imaging by providing real-time visualization of joint structures. Its accessibility and repeatability make it ideal for longitudinal monitoring, particularly in children. When combined with clinical scores such as the HJHS, ultrasound enhances diagnostic sensitivity and allows for more dynamic assessment of disease progression and treatment response [58].

MRI remains indispensable for comprehensive evaluation, particularly in research settings and complex clinical cases. It provides detailed assessment of cartilage integrity, hemosiderin deposition, and subchondral bone changes that are not fully captured by other modalities. However, due to practical limitations, MRI is best utilized selectively within a multimodal framework rather than as a standalone routine tool [59].

Functional assessment adds a critical dimension by linking structural joint changes to real-world outcomes. Discrepancies between imaging findings and functional status are not uncommon, particularly in early disease, underscoring the importance of incorporating patient-reported and performance-based measures. This ensures that management strategies are aligned not only with structural preservation but also with maintaining independence and quality of life [60].

The presence of inhibitors further reinforces the need for a multimodal strategy. Inhibitor-positive patients often exhibit discordance between clinical findings and underlying joint pathology due to variable bleeding patterns and treatment responses. Frequent and integrated assessments are necessary to accurately monitor disease progression and guide individualized therapeutic adjustments in this high-risk group [61].

From a clinical perspective, the implementation of a multimodal assessment approach supports **personalized medicine in hemophilia care**. By combining data from multiple sources, clinicians can stratify patients based on risk, detect early joint changes, and tailor interventions accordingly. This approach is particularly relevant in the era of novel therapies, where traditional markers of disease activity may not fully reflect treatment efficacy [62].

Future directions in multimodal assessment include the integration of digital health technologies, artificial intelligence in imaging interpretation, and the development of composite scoring systems that unify clinical, imaging, and biomarker data into a single standardized framework. Such advancements have the potential to enhance diagnostic accuracy, improve monitoring, and facilitate more precise and individualized management strategies [63].

Conclusion

In conclusion, a multimodal assessment approach represents the most comprehensive and clinically effective strategy for evaluating musculoskeletal status in pediatric hemophilia. By integrating clinical, radiologic, functional, and biological data, this approach overcomes the limitations of individual modalities and enables earlier detection, more accurate monitoring, and

optimized patient care. Its adoption is essential for improving long-term joint outcomes and advancing the standard of care in children with hemophilia.

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