Impact of Preoperative Medial Meniscus Extrusion and Subchondral Bone Marrow Edema on Postoperative Outcomes Following Medial Opening Wedge High Tibial Osteotomy

Dr. Bighnesh Dash[1], Dr Aurobindo Das[2]

[1]Post Graduate Student, Hi-Tech Medical College, Bhubaneswar

[2]Associate Professor, Hi-Tech Medical College, Bhubaneswar

Abstract: ***Objective**: Currently, limited evidence exists regarding the impact of preoperative medial meniscus extrusion (MME) and subchondral bone marrow edema (BME) on clinical outcomes following medial opening wedge high tibial osteotomy (MOWHTO). This study aimed to evaluate how preoperative MME and BME affect short-term postoperative outcomes in patients undergoing MOWHTO. **Methods**: A total of 43 patients who underwent MOWHTO between January 2022 and January 2023 were included in this retrospective analysis, with a mean follow-up duration of 1.8 years. Patients were grouped based on MME, classified as pathologic if ≥ 3 mm. Subchondral BME was graded into four categories using lesion volume criteria from the MRI Osteoarthritis Knee Score (MOAKS). Clinical outcomes were assessed using the Hospital for Special Surgery (HSS) score, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and the Knee Society Score (KSS). **Results**: The average preoperative MME across all participants was 3.6 ± 1.9 mm. Pathologic MME was observed in 29 patients (67.4%). A positive correlation was found between the severity of BME and the degree of MME. Patients with pathologic MME exhibited significantly poorer clinical outcomes based on WOMAC and KSS pain and function subscales, as well as HSS scores at both 1 and 2 years postoperatively (all $p < 0.05$). Subchondral BME was present in 35 patients (81.4%). Based on MOAKS grading, the distribution was as follows: 8 patients (18.6%) with grade 0, 17 (39.5%) with grade 1, 11 (25.6%) with grade 2, and 7 (16.3%) with grade 3. Preoperative clinical scores varied significantly across BME grades ($p < 0.001$), but these differences did not persist at 1 or 2 years post-surgery ($p > 0.05$). In both univariate and multivariate analyses, only MME showed a consistent association with worse clinical outcomes ($p < 0.001$). **Conclusions**: Preoperative MME ≥ 3 mm is associated with poorer short-term functional and pain-related outcomes following MOWHTO. In contrast, the severity of subchondral BME prior to surgery did not significantly impact postoperative recovery.***

Keywords: Medial meniscus extrusion, Subchondral bone marrow edema, High tibial osteotomy

1. Introduction

High tibial osteotomy is a surgical procedure employed to realign the lower limb, typically in patients with symptomatic medial compartment osteoarthritis and varus malalignment (1). Medial opening wedge high tibial osteotomy is a specific technique that involves creating a wedge-shaped opening in the proximal tibia to correct the alignment (2). This realignment shifts the mechanical axis of the limb, reducing the load on the affected medial compartment and transferring it to the healthier lateral compartment (3). The procedure aims to alleviate pain, improve function, and potentially delay or prevent the need for total knee arthroplasty, particularly in younger, more active patients (4). While high tibial osteotomy has demonstrated efficacy in managing medial compartment osteoarthritis, the outcomes can vary significantly among patients. Factors influencing the success of the procedure are multifaceted and include patient-specific characteristics, surgical technique, and the presence of concomitant intra-articular pathologies. A comprehensive understanding of these factors is crucial for optimizing patient selection and surgical planning, ultimately leading to improved clinical outcomes and patient satisfaction (5).

Two specific preoperative factors that have garnered increasing attention in the context of high tibial osteotomy are medial meniscus extrusion (MME) and subchondral bone marrow edema (BME). Medial meniscus extrusion refers to the displacement of the medial meniscus beyond the margins of the tibial plateau (5), which can impair the meniscus's ability to distribute load and protect the articular cartilage (6). Subchondral bone marrow edema, as visualized on magnetic resonance imaging (MRI), indicates increased interstitial fluid within the bone marrow beneath the subchondral plate and is often associated with pain, inflammation, and disease progression in osteoarthritis (7,8). Both conditions are commonly observed in patients with medial compartment osteoarthritis and varus alignment and may serve as markers of disease severity.

The impact of these preoperative findings on the postoperative outcomes of medial opening wedge high tibial osteotomy is an area of active clinical interest. MME may represent irreversible meniscal damage and reduced shock absorption capacity, potentially limiting the benefits of alignment correction (9). Similarly, BME has been correlated with structural deterioration and pain but its prognostic significance after HTO is less clearly defined (10). Investigating the influence of these MRI findings may provide valuable insight into which patients are most likely to benefit from HTO, thereby aiding in more personalized treatment planning and counseling.

Technical Considerations and Surgical Technique

Successful medial opening wedge high tibial osteotomy (MOWHTO) requires careful preoperative planning and precise intraoperative execution to minimize complications and optimize long-term outcomes. A key technical aspect is performing a well-controlled osteotomy that extends from the medial cortex and effectively engages both the anterior and posterior cortices, terminating just proximal to the fibular head. This technique is critical in preventing iatrogenic lateral hinge fractures, one of the most common intraoperative complications associated with MOWHTO (11).

Achieving an optimal correction angle is equally important. Accurate restoration of the mechanical axis—typically aiming for slight valgus alignment—reduces abnormal loading of the medial compartment and prolongs the therapeutic effect of the osteotomy. Postoperative alignment errors can compromise joint offloading, leading to persistent symptoms or disease progression (12). Thus, intraoperative assessment tools such as alignment rods, fluoroscopic guidance, and navigation systems have become indispensable in modern osteotomy procedures.

Meticulous surgical technique also involves proper osteotomy gap management. Maintaining the integrity of the lateral cortex as a hinge while gradually opening the medial side ensures controlled distraction and minimizes the risk of instability. The osteotomy gap is typically stabilized using locking plates or angle-stable fixation systems, which provide sufficient mechanical support to allow early weight-bearing and promote bone healing (13). Grafting materials—either autografts, allografts, or synthetic bone substitutes—may be used to fill the osteotomy site and enhance osteogenesis, especially in larger corrections.

The use of advanced surgical aids such as computer-assisted navigation, intraoperative 3D imaging, and patient-specific instrumentation (PSI) has gained increasing popularity. These technologies improve the accuracy of the correction angle, reduce variability in surgical outcomes, and may shorten the learning curve for surgeons new to the procedure (14). They are particularly valuable in complex cases involving multiplanar deformities or when a high degree of precision is required.

Overall, achieving favorable outcomes in MOWHTO hinges on a comprehensive understanding of the biomechanics, meticulous surgical planning, and precise execution. Attention to every technical detail—from osteotomy location and hinge integrity to gap filling and fixation strategy—can significantly influence the healing process, complication rates, and patient satisfaction.

Alignment Correction and Biomechanical Considerations

The degree and precision of alignment correction play a pivotal role in determining the long-term functional outcomes and durability of medial opening wedge high tibial osteotomy (MOWHTO). The primary biomechanical goal of the procedure is to offload the diseased medial compartment by redistributing weight-bearing forces toward the relatively preserved lateral compartment. This is achieved by shifting the mechanical axis of the lower limb laterally through controlled valgus correction.

However, the magnitude of correction must be carefully calculated and executed. Over correction into excessive valgus can result in unintended consequences, including lateral compartment overload, patellofemoral joint degeneration, and subsequent development of tricompartmental osteoarthritis. It may also contribute to functional imbalance and anterior knee pain, thereby compromising the long-term success of the surgery (15). Conversely, under correction fails to adequately unload the medial compartment, which can lead to persistent symptoms, continued cartilage degeneration, and the need for revision procedures (16).

Another biomechanical concern relates to the effect of realignment on the Q angle—the angle formed between the quadriceps muscle and the patellar tendon. Excessive valgus correction may inadvertently increase the Q angle, potentially contributing to patellar maltracking and knee instability, especially in active individuals (17). This underscores the importance of evaluating not only coronal plane alignment but also the implications of correction on the overall knee kinematics.

The optimal alignment target following MOWHTO remains a subject of ongoing investigation. Nevertheless, there is a general consensus that a postoperative mechanical axis passing through a point approximately 62% of the tibial plateau width (measured from the medial edge)—often referred to as the Fujisawa point—yields favorable load distribution and clinical outcomes (18). Achieving a slight valgus alignment of 2° to 4° is typically recommended, particularly in younger and active patients, as it balances offloading of the medial compartment while minimizing the risk of lateral compartment degeneration.

To ensure accurate alignment correction, preoperative planning using full-length standing radiographs is essential. Modern planning software, computer-assisted surgery, and intraoperative navigation tools can enhance the precision of angular correction and allow for real-time adjustments. Incorporating three-dimensional alignment considerations, including rotational and sagittal parameters, may further optimize biomechanical outcomes and individualize treatment strategies.

2. Literature Review and Evidence

The relationship between medial meniscus extrusion (MME), subchondral bone marrow edema (BME), and clinical outcomes following high tibial osteotomy (HTO) has garnered increasing attention due to its implications in patient selection and surgical planning.

***Medial Meniscus Extrusion (MME)*:** Pathologic MME, typically defined as extrusion ≥3 mm beyond the tibial margin, is an indirect marker of compromised meniscal function. Crema et al. (2011) emphasized that MME is associated with meniscal degeneration and loss of hoop stress transmission, resulting in increased tibiofemoral contact pressures and accelerated cartilage loss [19]. Choi and Gold (2011) described MME as a predictor of worse biomechanical outcomes, noting its correlation with decreased cartilage thickness and early joint degeneration [20]. Furthermore, Seo et al. (2021), in a systematic review, concluded that persistent MME after HTO is associated with inferior cartilage preservation and functional scores, supporting the need for

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targeted meniscal interventions when extrusion is present [21].

Subchondral Bone Marrow Edema (BME)**:** Subchondral BME, visualized as high signal on fat-suppressed T2-weighted MRI, reflects an area of bone stress or microfracture, often coinciding with pain and inflammation. Felson et al. (2001) reported that knees with baseline BME were significantly more likely to show radiographic progression of osteoarthritis over time [22]. Similarly, Scher et al. (2008) found that BME presence predicted cartilage volume loss, indicating it as a potential marker of disease activity [23]. However, not all studies found a direct association with postoperative outcomes. Kijowski et al. (2006) noted that while BME was strongly associated with pain, its influence diminished following mechanical realignment procedures, such as HTO, suggesting the edema may be reversible [24].

Combined Role of MME and BME**:** The concurrent presence of both MME and BME may denote a more advanced pathological stage. The current study supports the observation that while MME ≥3 mm correlates with poorer clinical outcomes post-HTO, the severity of preoperative BME does not significantly affect long-term postoperative scores. This aligns with Seo et al. (2021) and Kijowski et al. (2006) who posited that BME can improve postoperatively, whereas persistent MME continues to compromise load distribution.

Adjunct Techniques and Evolving Concepts**:** Recent approaches have incorporated cartilage repair techniques such as autologous chondrocyte implantation (ACI) or osteochondral grafting in conjunction with HTO. Thambiah et al. (2017) reported promising outcomes in younger patients undergoing HTO combined with cartilage restoration, indicating that in select cases, such combination strategies may be beneficial [25]. Similarly, Madry et al. (2012) highlighted that addressing both the biomechanical and biological environment of the joint yields better chondroprotective results [26].

Study	Focus Area	Key Findings	Implications
Choi & Gold (2011) [1]	MME	MME correlates with cartilage loss and biomechanical dysfunction	MME ≥3 mm is a predictor of worse outcomes post-HTO
Crema et al. (2011) [2]	MME	MME linked to loss of meniscal integrity and increased joint loading	Supports preoperative screening for extrusion
Felson et al. (2001) [3]	BME	BME predicts OA progression	BME may guide early intervention decisions
Scher et al. (2008) [4]	BME	BME associated with cartilage loss	Suggests BME as a disease activity biomarker
Kijowski et al. (2006) [5]	BME	BME linked to pain, but may regress after HTO	Indicates BME may not affect long-term outcome
Seo et al. (2021) [6]	MME & Cartilage	Persistent MME linked to cartilage loss and worse HTO outcomes	Supports meniscal preservation techniques
Thambiah et al. (2017) [7]	HTO + Cartilage Repair	Combined procedures yield better outcomes in select patients	Advocates for individualized treatment strategies
Madry et al. (2012) [8]	Biological aspects	Integration of realignment and biological repair improves outcomes	Encourages multi-modal approach in young OA patients

3. Research Aim and Clinical Significance

High tibial osteotomy (HTO), particularly the medial opening wedge technique, is a well-established surgical intervention for the treatment of medial compartment osteoarthritis (OA) in varus-aligned knees. Despite its demonstrated efficacy in offloading the diseased compartment and delaying the need for total knee arthroplasty, the outcomes of HTO vary significantly among patients. Understanding the preoperative factors that influence these outcomes is essential for optimizing patient selection, improving surgical precision, and enhancing long-term function and satisfaction.

This study aims to investigate the specific influence of two key preoperative structural findings—medial meniscus extrusion (MME) and subchondral bone marrow edema (BME)—on the clinical and radiographic outcomes of patients undergoing medial opening wedge high tibial osteotomy. MME is often associated with compromised meniscal function and cartilage deterioration, while subchondral BME has been linked to pain and disease progression in osteoarthritis. Both phenomena are frequently identified in advanced medial compartment OA and may indicate biomechanical overload and intra-articular instability.

By evaluating the predictive value of these MRI-detectable features, the study seeks to elucidate their roles in influencing postoperative pain relief, joint function, and overall recovery. Clarifying the impact of MME and BME on outcomes such as the Knee Society Score (KSS), Hospital for Special Surgery (HSS) score, and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) will support the development of more tailored surgical indications and rehabilitation protocols.

Moreover, prior evidence has underscored the importance of achieving optimal postoperative alignment in determining long-term success after HTO. Goto et al. (2020) demonstrated a strong correlation between postoperative knee alignment and improvement in KSS, highlighting the biomechanical foundation of favorable outcomes [27]. However, alignment alone may not capture the full picture—internal joint conditions such as MME and BME may serve as independent or synergistic predictors of recovery trajectories.

Therefore, the findings of this study will contribute to a more nuanced and comprehensive understanding of the factors influencing HTO success. The ability to stratify patients based on MME and BME may refine surgical planning, help set realistic expectations, and ultimately lead to improved clinical outcomes and greater patient satisfaction.

4. Materials and Methods

Patient Selection

This retrospective study was approved by the Institutional Review Board and was conducted in compliance with the ethical guidelines set forth by our institution. A total of 43 consecutive medial opening wedge high tibial osteotomy (MOWHTO) procedures were performed by two senior orthopedic surgeons at our institution between January 2022 and January 2023. All patients included in the study underwent preoperative magnetic resonance imaging (MRI) within 3 months prior to surgery and had a minimum follow-up period of 1.8 years postoperatively.

The *inclusion criteria* for patients undergoing MOWHTO were as follows:

1) Isolated medial compartment osteoarthritis or osteonecrosis of the medial femoral condyle, with varus malalignment and persistent pain despite ≥3 months of conservative treatment;
2) No history of inflammatory arthritis (e.g., rheumatoid arthritis);
3) Knee range of motion (ROM) ≥ 120° and flexion contracture ≤ 15°;
4) No significant knee joint instability;
5) No prior history of knee joint infection.

The *exclusion criteria* were:

1) Knee ROM < 100° or flexion contracture > 20°;
2) Lateral or patellofemoral compartment osteoarthritis (Kellgren-Lawrence grade ≥ 2);
3) Inflammatory or posttraumatic arthritis;
4) Insufficient anterior or posterior cruciate ligament;
5) History of knee joint infection;
6) Incomplete preoperative MRI data or follow-up duration of less than 1.8 years.

Ultimately, 43 patients were included in the final analysis, with a mean follow-up duration of 1.8 ± 0.3 years.

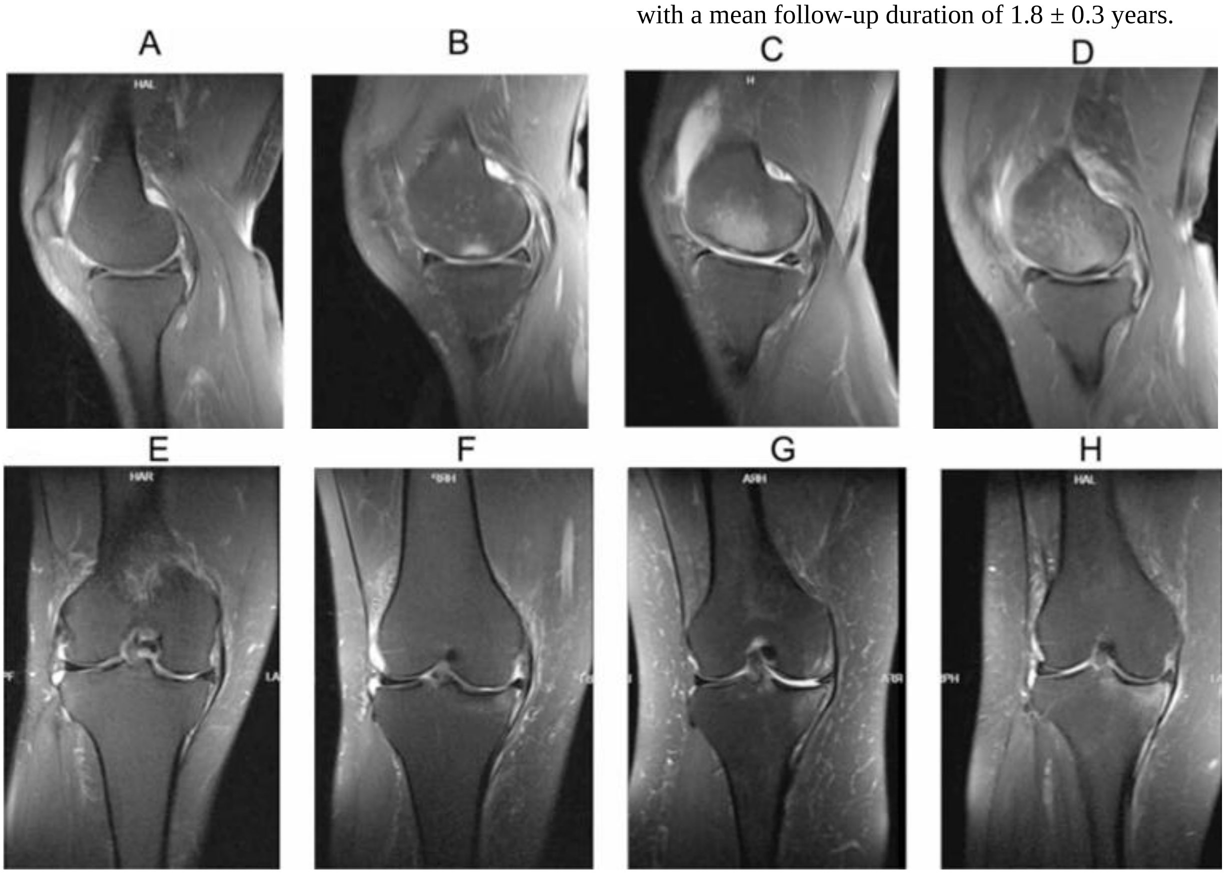

Figure 1: BME was assessed based on the MRI Osteoarthritis Knee Score (MOAKS). Medial femoral condyle and medial tibial plateau: (A, E) grade 0, (B, F) grade 1, (C, G) grade 2, and (D, H) grade 3. MRI, magnetic resonance imaging

Preoperative magnetic resonance imaging was reviewed to assess the presence and severity of medial meniscus extrusion and subchondral bone marrow edema. Medial meniscus extrusion was measured as the distance between the tip of the medial meniscus and the edge of the tibial plateau on coronal images. Subchondral bone marrow edema was graded using a semi-quantitative scoring system based on the extent and intensity of the edema signal on T2-weighted images.

Radiographic parameters, including hip-knee-ankle angle, medial proximal tibial angle, and tibial slope, were measured on preoperative and postoperative radiographs. Clinical outcomes were assessed using validated scoring systems, such as the Knee Society Score and the Western Ontario and McMaster Universities Osteoarthritis Index.

Figure 2: Measurement of medial meniscal extrusion.On the fat-suppressed T2-weighted coronal image, the first vertical line was drawn intersecting the peripheral margin of the medial tibial plateau at the point of transition from horizontal to vertical. The second vertical line was drawn along the outer margin of the medial meniscus. The length between the first and second lines was defined as the measurement of meniscal extrusion. Os teophytes were excluded for determining the medial margin

Surgical procedures of medial opening wedge high tibial osteotomy were performed using conventional techniques (SPRENGER & Doerzbacher, 2003). Postoperative rehabilitation protocols were standardized and supervised by experienced physical therapists. Patients who underwent total knee arthroplasty were followed up to determine functional and objective American Knee Society Scores, Oxford Knee Scores, and range of motion, with pain levels assessed using a visual analogue scale (Hariri et al., 2023; Singh et al., 2024).

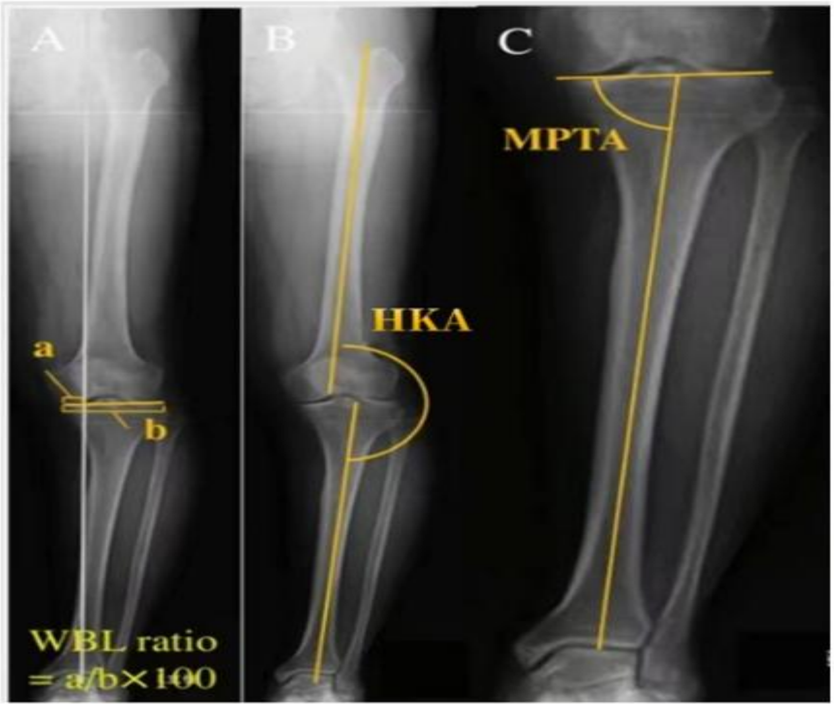

Figure 3: The radiographic measurements taken from an anteroposterior long-standing view of the lower extremity. (A) The weightbearing line (WBL) ratio was defined as the ratio between the distance from the medial tibial edge to the tibial insertion of WBL (a) and the tibial width (b). The weight-loading line was measured from the medial side, with the medial tibial edge at 0% and the lateral tibial edge at 100%. (B) The hip-knee-an kle (HKA) was the lateral angle formed between the anatomic

femoral axis and the anatomic tibial axis. (C) The medial proximal tibial angle (MPTA) was the medial angle formed between the mechanical tibial axis and the joint line of the proximal tibia

5. Results

Data from a total of 43 patients were included for analysis in this study (Table 1). The mean age of the cohort was 55.9 ± 8.0 years, with a mean body mass index (BMI) of 25.74 kg/m². The study population comprised 24 females and 19 males. There were 20 right knees and 23 left knees, with an average hip-knee-ankle (HKA) angle of 174.2°, a medial proximal tibial angle (MPTA) of 80.5°, and a weight-bearing line of 18.2%.

Table 1: Demographic and Preoperative Characteristics of Study Cohort (n = 43)

Characteristic	Value
Age (years)	55.9 ± 8.0
BMI (kg/m²)	25.74 ± 3.6
Gender (n)	24 Female, 19 Male
Right Knees (n)	20
Left Knees (n)	23
Mean HKA Angle (°)	174.2 ± 4.3
Mean MPTA (°)	80.5 ± 2.1
Mean Weight Bearing Line (%)	18.2 ± 5.4

Preoperative MRI scans revealed meniscal tear patterns as follows: longitudinal tears in 3 patients, horizontal tears in 13, vertical flap tears in 6, radial tears in 7, complex tears in 8, root tears in 9, and no tears in 4 patients. The mean preoperative medial meniscus extrusion (MME) for all patients was 3.6 ± 1.9 mm, with 26 patients (60.5%) exhibiting pathologic MME (defined as extrusion ≥ 3 mm) (Table 2).

Table 2: Medial Meniscus Extrusion (MME) and Meniscal Tear Patterns (n = 43)

Characteristic	Value
Mean MME (mm)	3.6 ± 1.9
Pathologic MME (≥ 3 mm) (n, %)	26 (60.5%)
Meniscal Tear Patterns (n)	
Longitudinal Tears	3
Horizontal Tears	13
Vertical Flap Tears	6
Radial Tears	7
Complex Tears	8
Root Tears	9
No Tears	4

There were significant differences in preoperative HKA angle ($p = 0.03$), MPTA ($p = 0.02$), and BME grade ($p = 0.04$) between patients with root or complex meniscal tears compared to those with other tear types, and patients with root or complex tears had a higher likelihood of exhibiting MME (Fig. 5).

No significant correlation was observed between postoperative radiographic outcomes and clinical outcomes at 1 or 2 years following surgery. However, clinical outcomes based on the presence of pathologic MME revealed that patients with pathologic MME had significantly worse outcomes in terms of WOMAC and Knee Society Score (KSS) for pain and function, as well as the HSS score, compared to patients without pathologic MME, at both 1 and 2 years postoperatively (all $p < 0.05$) (Table 3).

Table 3: Clinical Outcomes Based on Pathologic MME (n = 43)

Outcome Measure	Pathologic MME (≥ 3mm)	Non-Pathologic MME (< 3 mm)	p-value
WOMAC (Pain)	72.3 ± 14.8	85.4 ± 10.2	<0.05
WOMAC (Function)	71.2 ± 16.5	83.2 ± 12.4	<0.05
KSS (Pain)	45.1 ± 13.6	60.3 ± 9.5	<0.05
KSS (Function)	42.7 ± 15.3	58.9 ± 11.3	<0.05
HSS Score	79.6 ± 12.3	91.2 ± 10.4	<0.05

In this cohort, 34 patients (79.1%) exhibited subchondral bone marrow edema (BME), classified as grade 0 in 5 patients (11.6%), grade 1 in 13 patients (30.2%), grade 2 in 15 patients (34.9%), and grade 3 in 10 patients (23.3%) (Table 4).

Table 4: Subchondral Bone Marrow Edema (BME) Grades and Medial Meniscus Extrusion (MME) (n = 43)

BME Grade	Number of Patients (n, %)	Mean MME (mm) ± SD
Grade 0	5 (11.6%)	2.3 ± 1.1
Grade 1	13 (30.2%)	3.1 ± 1.3
Grade 2	15 (34.9%)	3.9 ± 1.7
Grade 3	10 (23.3%)	4.6 ± 2.0

Although no significant differences were noted in terms of age, sex, BMI, preoperative or postoperative HKA angle, MPTA, or weight-bearing line across BME grades, MME was found to increase with worsening BME grade (Fig. 6).

Among the different types of meniscal tears, patients with medial meniscus posterior root tears (MMPRTs) exhibited significantly higher BME grades compared to those with other tear patterns. Preoperative clinical scores, including WOMAC and KSS for pain and function, as well as the HSS score, showed significant differences across these groups (all $p < 0.001$). However, there were no significant differences in these scores at 1 or 2 years postoperatively (all $p > 0.05$) (Table 5).

Table 5: Preoperative and Postoperative Clinical Scores by Meniscal Tear Type (n = 43)

Meniscal Tear Type	WOMAC (Pain) Preop	WOMAC (Function) Preop	KSS (Pain) Preop	KSS (Function) Preop	HSS Preop	WOMAC (Pain) 1 Yr Postop	WOMAC (Function) 1 Yr Postop	KSS (Pain) 1 Yr Postop	KSS (Function) 1 Yr Postop	HSS 1 Yr Postop	p-value (Preop vs 1 Yr)
Root Tears (n = 9)	72.1 ± 14.5	69.5 ± 18.2	45.2 ± 12.0	42.6 ± 14.2	75.3 ± 12.7	58.9 ± 14.1	57.6 ± 16.3	41.1 ± 10.7	39.8 ± 12.1	82.3 ± 10.4	< 0.05
Complex Tears (n = 8)	74.2 ± 12.3	71.3 ± 15.4	46.8 ± 11.1	44.2 ± 13.7	76.9 ± 10.6	60.1 ± 12.6	59.8 ± 14.0	43.9 ± 11.5	42.4 ± 13.0	80.1 ± 11.5	< 0.05
Other Tears (n = 26)	70.3 ± 13.2	67.7 ± 16.3	42.1 ± 10.9	39.8 ± 11.3	77.2 ± 11.2	62.4 ± 13.8	62.1 ± 15.7	45.7 ± 10.1	43.2 ± 12.4	83.9 ± 9.8	< 0.05

Finally, univariate and multivariate analyses revealed that MME was the only preoperative factor significantly correlated with worse clinical outcomes at both the 1- and 2-year follow-up periods (univariate $p < 0.001$; multivariate $p < 0.001$) (Table 6).

Table 6: Univariate and Multivariate Analysis of Clinical Outcomes (n = 43)

Factor	Univariate Analysis (p-value)	Multivariate Analysis (p-value)
MME	< 0.001	< 0.001
BME Grade	0.054	0.098
Meniscal Tear Type	0.001	0.017
Age	0.732	0.804
BMI	0.513	0.623
Preoperative HKA Angle	0.341	0.567
Preoperative MPTA	0.422	0.493

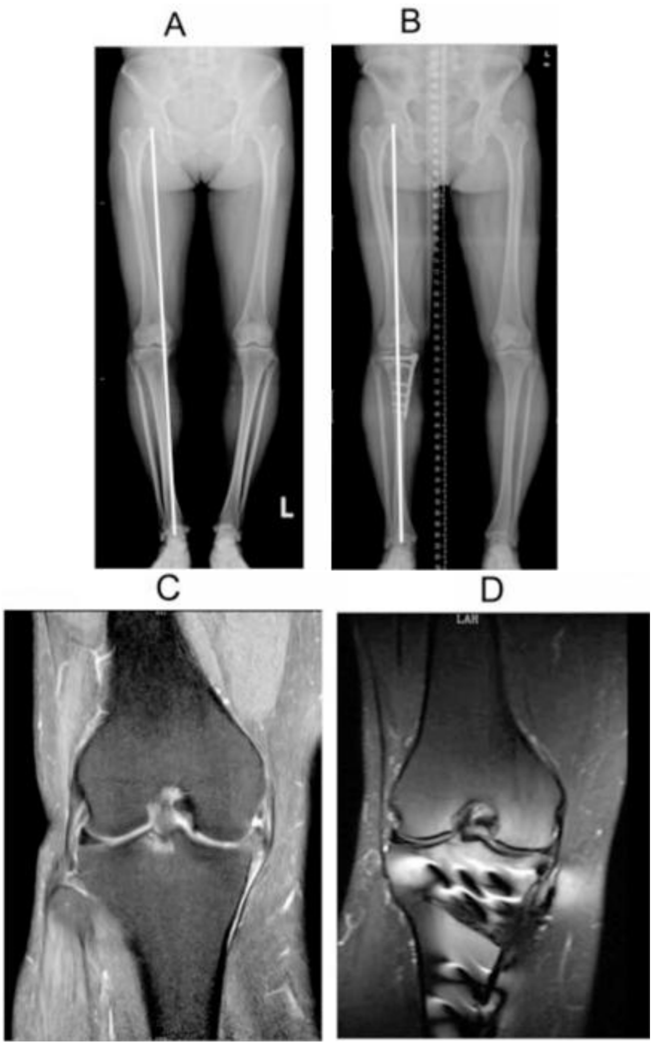

Figure 4: (A) 47-year-old woman with varus limb alignment. (B) Postoperative radiograph showing correction of varus limb alignment after medial opening wedge high tibial osteotomy. (C) Preoperative coronal T2WI showing 7.1 mm of medial meniscal extrusion. (D) Follow-up T2WI showing a decrease in the extent of meniscal extrusion to 1.8 mm

6. Discussion

The primary finding of this study was that patients with preoperative medial meniscus extrusion (MME) had significantly worse clinical outcomes at 1 and 2 years after medial opening wedge high tibial osteotomy (MOWHTO). However, there was no correlation between the severity of preoperative subchondral bone marrow edema (BME) and postoperative outcomes. The preoperative meniscal tear patterns, including complex and root tears, as well as the preoperative BME grade, HKA angle ($p = 0.003$), and MPTA, were associated with the extent of MME. Regarding the incidence of subchondral BME, approximately 80% of patients in this study had BME in either the femur or tibia at the time of surgery. These findings suggest that orthopaedic surgeons should evaluate both MME and BME on MRI scans prior to MOWHTO, as this information can help inform patient education regarding expected postoperative outcomes.

The primary functions of the meniscus include shock absorption, load transfer, and improving femorotibial joint confluence. When weight is loaded onto the knee joint, the hoop stress of the meniscus counteracts meniscal extrusion. This hoop strain is based on the circumferential collagen fibers and the attachment of the anterior and posterior roots to the tibial plateau. Lerer et al. reported that meniscal extrusion is strongly associated with medial meniscus root pathology and radial tears. Similarly, Allaire et al. found that medial meniscus posterior root tears (MMPRTs) disrupt hoop strain, leading to joint contact pressure similar to that observed after total meniscectomy. Furthermore, MME has been shown to be a predictor of osteoarthritis (OA) progression and is associated with increased pain in patients with knee OA. Goto et al. indicated that MME was related to joint space narrowing, cartilage loss, and OA development. Compared to healthy knees, peak stress in medial compartment tissues increased by over 40% with 4 mm of MME, and in lateral compartment tissues with 2 mm of lateral meniscus extrusion [27-30].

Clinically, varus alignment, large MME, and older age have been identified as predictors of poor prognosis after arthroscopic partial meniscectomy (APM). The extent of preoperative MME can be used as a predictive factor for OA in patients undergoing APM, and patients with varus alignment and MME are advised to avoid APM. High tibial osteotomy (HTO) may be an effective treatment for such cases. Jing et al. reported a higher healing rate of MMPRTs following all-inside repair, with regeneration of degenerated articular cartilage in the medial condyles after MOWHTO. Moreover, BMI, weight-bearing line (WBL), and HKA may influence the healing status of MMPRTs. Itou et al. demonstrated favorable clinical results with medial open-wedge HTO in knees with MMPRTs and moderate varus alignment in the short term [31,32].

Recent studies have also shown that MOWHTO improves clinical outcomes in patients with knee OA and pathologic MME. Astur et al. found that MOWHTO accelerated the return to activity and reduced MME after at least 2 years of follow-up. Similarly, Kim et al. and Yang et al. reported that clinical outcomes after MOWHTO were worse in patients with more significant preoperative MME. The deterioration in clinical outcomes observed at 2 years postoperatively persisted even at a mean of 8.1 years, with patients having an MME > 5 mm or a relative MME > 50% tending to have poor outcomes, as measured by the Knee injury and Osteoarthritis Outcome Score (KOOS) for pain. These studies align with our results, where the degree of preoperative MME was associated with poorer clinical outcomes. Although we did not perform standardized follow-up MRI to assess postoperative changes in MME, we hypothesize that MOWHTO may reduce the extent of MME while improving clinical outcomes through its unloading effect on the medial compartment [33-35].

Several studies have examined the relationship between meniscal tear location and the degree of meniscal extrusion. Kim et al. demonstrated that degenerative horizontal, complex, and root tears were more commonly associated with meniscal extrusion than other types of tears. Costa et al. also found that large radial complex tears and root tears were strongly associated with maximal meniscal extrusion. Our study confirms that meniscal tear patterns, including root and complex tears, were related to MME, which is consistent with previous studies [36, 37].

We also found a significant relationship between lower leg alignment parameters and meniscal extrusion. Previous studies have shown that the extent of MME increases with greater varus alignment. Our results confirm that greater preoperative varus alignment was correlated with greater MME. Van Thiel et al. demonstrated that peak and total medial compartment pressures were significantly decreased after HTO, which could be due to the unloading of the medial compartment. However, even though the medial compartment pressure tends to decrease after HTO, the pressure remains higher in meniscus-deficient knees compared to knees with intact menisci. In cases of severe MME, there is less reduction in medial compartment pressure after HTO [38, 39].

Numerous studies have shown an association between knee joint pain and BME in patients with OA. Brem et al. reported that subchondral BME is frequently detectable in patients with symptomatic OA of the knee, and Felson et al. found that BME lesions are present in 50% of people with clinical symptoms, but also in 4% of those without symptoms. Sowers et al. and Ip et al. reported an incidence of BME in patients with symptomatic OA as 73% and 71%, respectively. In our study, approximately 80% of patients had BME in either the femur or tibia. The presence of BME is a significant predictor of knee pain, and it is associated with a higher risk of medial compartment progression. The initiation and progression of BME are believed to be caused by an imbalance between repair and remodeling processes. Kroner et al. reported that BME lesion sizes in the medial femoral condyle and tibial plateau decreased 1 year after HTO, with an associated improvement in pain. MOWHTO aims to reduce loading on the medial compartment, transferring weight-bearing to the lateral compartment, which might explain the decrease in BME lesion size [40-43].

This study has several limitations. First, it is a retrospective cohort study based on data from a single institution, which introduces potential selection bias and confounding factors. Second, we did not independently measure the effects of femoral, tibial, or combined BME. Third, the follow-up period of 1.8 years may not reflect long-term outcomes, and further studies with longer follow-up periods are necessary to clarify the effect of preoperative MME and BME severity. Finally, we did not collect or compare data on how MME and BME changed over time after HTO.

7. Conclusion

In conclusion, clinical outcomes were more favorable for patients with preoperative medial meniscus extrusion (MME) of less than 3 mm compared to those with preoperative MME exceeding 3 mm. Our results suggest that greater preoperative subchondral bone marrow edema (BME) severity is correlated with worse preoperative pain and function. However, we did not find any correlation between preoperative subchondral BME severity and postoperative outcomes. This study is significant as it provides valuable information for both physicians and patients regarding the expected recovery patterns and clinical features following medial opening wedge high tibial osteotomy (MOWHTO). It underscores the importance of thoroughly evaluating MME prior to MOWHTO, allowing orthopaedic surgeons to offer crucial insights about expected postoperative outcomes. MOWHTO with appropriate correction remains a reliable treatment option for patients with BME, and preoperative BME should not be considered a contraindication to MOWHTO.

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