Characteristic of Knee Joint Loading and Muscle Activation in Knee Osteoarthritis Patients with Bone Marrow Lesions

Kojima Satoshi[1], Motoki Kuroo[1], Jun-ichi Hata[2], Yuna Usami[1], Takahito Nakamura[1,3], Takanori Kokubun[1,3]
[1]Graduate School of Health, Medicine, and Welfare, Saitama Prefectural University, Saitama, Japan, [2]Graduate School of Human Health Sciences, Tokyo Metropolitan University, Tokyo, Japan, [3]Department of Physical Therapy, School of Health and Social Services, Saitama Prefectural University, Saitama, Japan,
Email: 2681305p@spu.ac.jp

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INTRODUCTION:
Bone Marrow Lesion (BML) is a significant MRI finding associated with Knee Osteoarthritis (KOA), contributing to joint pain and accelerating disease progression. They typically appear deeper than cartilage, frequently in the medial condyle of the femur and tibia. Previous studies have suggested a potential link between BML and mechanical stress within the joint. Furthermore, animal studies have demonstrated that compressive stress can affect subchondral bone[(1, 2], supporting the hypothesis that abnormal mechanical loading during gait may contribute to the development or progression of BMLs by increasing localized subchondral stress. However, despite these insights into the effects of mechanical loading on subchondral bone, it remains unclear how walking patterns that induce such mechanical stress differ in terms of joint kinematics and muscle activation between individuals with BML and those without.
This study aimed to clarify the gait patterns and muscle coordination strategies specific to individuals with BML by comparing knee kinematics, ground reaction forces, and electromyographic (EMG) activity during walking between a BML group and a healthy control group.

METHODS:
The study included four adults with BMLs identified on MRI (BML group) and three age- and sex-matched healthy adults (six knees, Control group). MRI scans were performed using a 3.0 Tesla MRI scanner (GE Healthcare), and BMLs were defined as poorly marginated areas of increased signal intensity in the epiphyseal marrow on proton density fat-suppressed 3D Fast Spin Echo images. Regions of interest (ROIs) were drawn using OsiriX MD analysis software, and lesion volumes were calculated using the software's automated volume function (summed if multiple BMLs were present).
Gait analysis was conducted while participants walked at their preferred speed on an instrumented treadmill (Bertec) with embedded force plates, and a 3D motion analysis system (VICON) was used. Joint angles and joint moments of the knee were computed from marker coordinate data and ground reaction forces. Rigid body models for each segment were generated using the Optimal Common Shape Technique (OCST) to reduce the influence of skin movement artifacts. The hip joint center was estimated using the Symmetrical Center of Rotation Estimation (SCoRE) algorithm based on star-arc movements, and the functional knee joint axis was calculated using the Symmetrical Axis of Rotation Approach (SARA) based on flexion-extension movements.
Fifteen gait cycles were extracted for each participant, and stance-phase averages were used to calculate the mean, maximum, and minimum knee flexion angles, as well as knee extension and valgus moments. Surface EMG was used to analyze muscle activity in the gluteus maximus, tensor fasciae latae, quadriceps, hamstrings, and gastrocnemius muscles. Correlation coefficients were computed between BML volumes and gait/muscle parameters, and comparisons were made between the two groups. This study was approved by the Ethics Committee.

RESULTS:
In the BML group, the knee flexion angle during the early stance phase was significantly greater than that of the Control group, while the knee extension moment showed a decreasing trend. Regarding joint loading, both the average and minimum values of knee joint compressive force were higher in the BML group than in the Control group, suggesting the presence of sustained compressive stress.
Surface EMG analysis showed increased hamstring activity in the BML group, particularly during the initial stance phase. Elevated activity was also observed in the gastrocnemius muscles, indicating changes in muscle coordination patterns.
In addition, analysis of the relationship between BML volume and gait parameters revealed a positive correlation tendency with the maximum knee flexion angle and the minimum compressive force. These findings suggest that the accumulation of mechanical stress in the knee joint may be associated with the presence and progression of BMLs.

DISCUSSION: Our findings indicate that individuals with BML adopt a gait strategy characterized by increased knee flexion and decreased extension moment during early stance. This pattern may represent a neuromechanical adaptation to minimize joint loading and protect the affected structures. The elevated joint compressive forces observed in the BML group imply that persistent mechanical stress may contribute to the development or progression of BML and associated symptoms.
Additionally, the increased hamstring activity observed in the BML group could represent a neuromuscular adaptation aimed at stabilizing the joint through co-contraction, compensating for reduced extensor function. While this strategy may enhance joint stability in the short term, it may also lead to altered load distribution across the joint and contribute to long-term dysfunction or pain. These results highlight the importance of evaluating both kinetic and muscular factors in BML pathology.
This study demonstrates that individuals with BML exhibit distinctive biomechanical and neuromuscular adaptations during gait, including increased knee flexion, reduced extension moment, elevated joint compressive forces, and altered muscle activation patterns. These findings suggest a redistribution of mechanical loads and neuromuscular reorganization in the presence of BML, offering new insights into its pathophysiology. Further large-scale and longitudinal studies are warranted to deepen the understanding of gait alterations in BML and develop targeted interventions for early management and prevention.

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