골관절염 치료용 무릎보조기의 최적 힌지각 디자인 개발

Optimal Hinge Design of Knee Braces for the Treatment of Knee Osteoarthritis

*박명형[1], #김철웅[1,2], 양영규[1], 이순혁[3]
*Myung-Hyung Park[1], #Cheol-Woong Kim(woong25@korea.ac.kr)[1,2], Young-Gyu Yang[1], Soon-Hyuk Lee[3]
[1](주)트리플씨메디칼 R&D Center, [2]고려대학교 공학기술연구소, [3]고려대학교 의과대학 정형외과

Key words : OA Knee Brace, Osteoarthritis, Anatomical Knee Motion, 6 DOF Hinge, Motion Analysis

1. Introduction

Osteoarthritis (OA) is a disease developed by multiple factors such as biological and mechanical events. Recent survey said that almost 10% of entire population in the world developed OA, and about 50% of old people aged over 50 are suffering from the disease. With increasing life spans, the number of OA patient is still increasing. Osteoarthritic diseases occur in the knees, hands, hips, and even spine, and knee OA takes the largest proportion among them. The symptom of knee OA is mainly manifested by the degeneration of articular cartilage, and it will be accelerated by other damages on the subcondral bone, synovium, and ligaments. Sometimes, it is associated with acute inflammation that leads to painful joint motion. One of the most common causes of knee OA is the varus-valgus laxity of the knee defined as the unstable knee. Radiographic diagnosis of knee OA showed that knees with OA had narrowed joint space and osteophyte formation at the tibiofemoral compartments. Chronic pain and joint stiffness limit the range of motion of OA patients' knees, and reduced activities will worsen the degree of the instability of their knees. For the elderly, knee OA is the main reason why they are more likely to fall than the young. Biomechanical studies on the knee have showed that medial knee loading among the healthy subjects is about 60% during stance but, in most OA knees, it increases up to 100%. This result is related to the malalignment of the femur and tibia. The reduced and even no joint space between the femur and tibia in the medial compartment of the knee results in a varus deformity in the coronal plane. Theoretically, OA knee braces, which adopt a three-point leverage system to generate external force on the opposite site of the affected compartment of the knee, can reduce the mechanical loading during gait so that they can slow down or stop the progression of OA. Many radiographic studies and gait analyses presented that 'off-loading force' produced by OA knee braces could widen the narrow joint space. Moreover, those studies demonstrated that the patients with OA experienced less pain overall, increased balance, and sense of security. However, in the long-term follow-up study averaged 3 years, only 41% of 29 patients answered that they were still using the braces, and others quit wearing them or had arthroplasty. Other studies showed that clinical effectiveness of the OA knee braces remained questionable and hinge misalignment could even damage to uninjured knees. Through the literature searches and product analyses, we hypothesized that increasing the efficacy of wearing OA knee braces may be closely related to the design of the knee brace hinge because a non-anatomically designed hinge can hamper the natural movement of the knee.

2. 6 DOF of the Knee Joint and Its Kinematics

The knee is one of the most complex joint in our body and its movement is determined by the geometry of the joint surface, especially tibial surface, the ligaments that restraint the passive motion of the joint, and muscle force. The kinematic studies showed that the knee joint has 6 degrees of freedom, three rotations and three translations. Fig. 1 shows a diagram of the knee joint with 6 DOF.

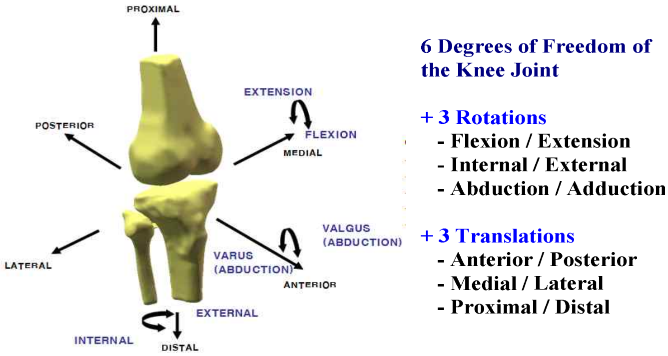

Fig. 1 A diagram of the anatomical movement of the knee joint.

However, full degrees of freedom do not have to be always measured; for instance, medial and lateral translations are accompanied by abduction and adduction, and proximal and distal translations are significantly influenced by the loading condition that varies with types of activity such as jumping, and the surface of the ground. In this study, we only considered internal/external rotation and anterior/posterior translation directly coupled to flexion and extension angles of the knee. There are many kinds of OA knee braces in market and their hinges can be categorized by two types of the joint model; one is a pivot hinge or a hinge joint, and the other is a planar joint. First, a pivot hinge can only satisfy the flexion and extension, just connecting the frames or shells on the thigh and the shank of the lower extremity. It provides abnormal restriction to the knee joint that may be detrimental to the knee with the long-term use. In the case of a planar joint, it permits the anterior/posterior translation coupled to the flexion of the knee but it does not allow the internal/external rotation which is obviously observed during both passive and dynamic flexion. Recently, the knee has been modeled as a 6 DOF spatial joint because this kind of joint gives maximized degrees of freedom between the two bodies. However, all kinematic data collected from the joint model provide too much and even difficult information to derive clinically important output. As mentioned above, for the development of a hinge for an OA knee brace, two kinds of translation do not have to be included, and furthermore, abduction/adduction can also be ignored because the main function of the OA knee brace is to reduce the load in the affected compartment. For example, if the brace provides the normal varus moment to the knee with OA in the medial side during walking, it will result in more rapid progression of the OA. The kinematic data of the knee movement can be measured by CT, RSA, MRI, or motion analysis in which reflective markers and electrogoniometers are used to estimate the angular movement of the knee. From the former three methods, only static images are obtained but with some combination of those, 3D images and motion data can be measured. Motion analysis provides more reliable results of the dynamic knee motion during walking, jumping, or other activities but has some limitations like ethical issues and a small number of subjects in a study.

3. Passive and Dynamic Movement of the Knee

Wilson *et al.* measured the passive movements of fifteen post-mor-

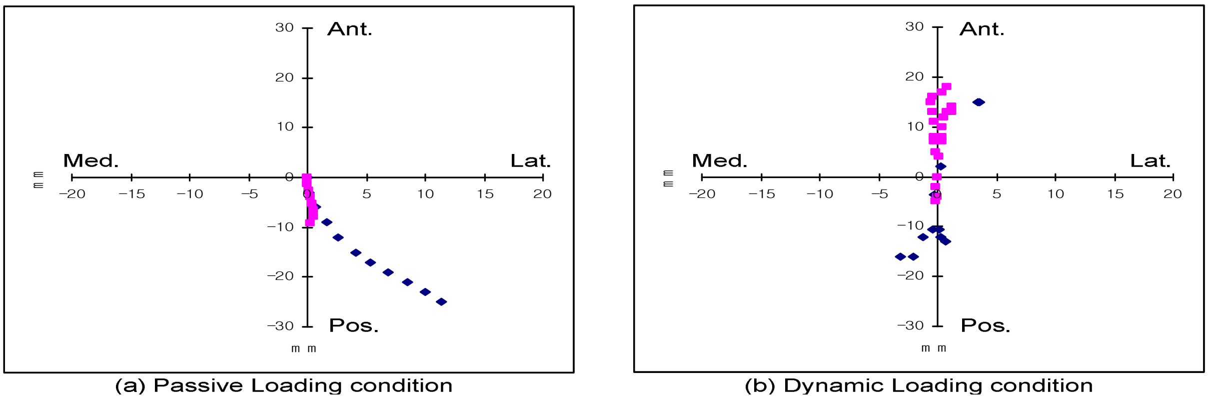

Fig. 2 The center of movement of the knee joint in the transverse plane during passive and dynamic loading. (a) Traces of the knee movements in the weight bearing (■) and non-weight bearing (◆) conditions, (b) Traces of the knee movements from two different gait analyses.

tem human knee specimens using a designed testing rig. With passive flexion of the knees, the measured internal rotation ranged from 14° to 36°, and the posterior translation ranged from 20 to 34 mm while the reference point where the anterior cruciate ligament placed at the most posterior point on the tibia moved posteriorly, proximally, and medially. Iwaki et al. presented that from the hyperextension to full passive flexion (-5° to 120°), the femoral condylar translation was more dominant in the lateral plane (about 18 mm) than in the medial plane (about 3 mm). This means that the internal rotation of the tibia during flexion is apparent and then the center of rotation moves posteriorly. However, those results can not be applied directly to the dynamic loading condition in the knee during gait (Fig. 2). Although the maximum values of anterior translation and internal rotation of the tibia were observed in the swing phase where the flexion angle reached the maximum value, about 60°, the changes of anterior/posterior translation and internal/external rotation showed quite different patterns from those of the passive flexion of the knee. The flexion angle reached the first plateau (about 20°) and then decreased until around 45% of the gait cycle while the posterior translation and the internal rotation kept increasing. From the heel strike phase to the terminal extension phase, the knee should accept the moments acting on the joint posteriorly and internally. Thus, the knee shows inconsistent kinematic data with those from other weight bearing conditions against gravity like squatting, and non-weight bearing condition.

4. Conclusion

It is difficult to design a hinge for the knee which demonstrates complex motion because it has not only more degrees of freedom than most other joints but also its movement is determined by the surface and even size of the knee joint which varies person by person. A simple hinge joint has been widely used for the whole body analysis in various situations like crash test. However, it does not give us the detailed information about the knee movement but just works as a part of the structure. Most literatures that presented the pros and cons about the clinical effect of OA knee braces are likely to focus on the change of the varus moment during stance or gait, the degrees of the joint space expansion, and scores from a visual analog scale (VAS). Muscles and skins on the lower extremity may compensate the abnormal movement of the knee due to the non-anatomically designed hinge of an OA knee brace but it will gradually damage other tissues during its long-term use. Especially, OA braces should be tightly fixed to maximize the off-loading force to the affected compartment. Therefore, appropriately designed hinges are more necessary for the brace than other kinds of brace such as prophylactic braces. To design an optimal knee brace hinge, at least, internal/external rotation and anterior/posterior translation should be considered among other degrees of freedom except flexion and extension.

Acknowledgements

This work was supported by a grant from the Ministry for Health, Welfare and Family Affairs, Korea (Project no. A084306).

References

1. Andriacchi, T. P. and Dyrby, C. O., "Interactions between Kinematics and Loading during Walking for the Normal and ACL Deficient Knee," *Journal of Biomechanics*, 38, pp. 293-298, 2005.
2. Bull, A. M. J. and Amis, A. A., "Knee Joint Motion : Description and Measurement," *Proc Instn Mech Engrs*, Vol. 212, pp. 357-372, 1998.
3. Davidson, P. L., Sanderson, D. J., and Loomer R. L., "Kinematics of Valgus Bracing for Medial Gonarthrosis: Technical Report," *Clinical Biomechanics*, 13, pp. 414-419, 1998.
4. Freeman, M. A. R., "How the Knee Moves," *Current Orthopaedics*, 15, pp. 444-450, 2001.
5. Freeman, M. A. R. and Pinskerova, V., "The Movement of the Normal Tibio-femoral Joint," *Journal of Biomehanics*, 38, pp. 197-208, 2005.
6. Johal, P., Williams, A., Wragg, P., Hunt, D., and Gedroyc, W., "Tibio-femoral Movement in the Living Knee," *Journal of Biomechanics*, 38, pp. 269-276, 2005.
7. Koo, S. and Andriacchi, T. P., "The Knee Joint Center of Rotation is Predominantly on the Lateral Side during Normal Walking," *Journal of Biomechanics*, 41, pp. 1269-1273, 2008.
8. McPherson, A., Karrholm, J., Pinskerova, V., Sosna, A., and Martelli, S., "Imaging Knee Position using MRI, RSA/CT and 3D Digitisation," *Journal of Biomechanics*, 38, pp. 263-268,2005.
9. Sarzi-Puttini, P., Cimmino, M. A., Scarpa, R., Caporali, R., Parazzini, F., Zaninelli, A., Atzeni, F., and Canesi, B., "Osteoarthritis: An Overview of the Disease and Its Treatment Strategies," *Seminars in Arthritis and Rheumatism*, 35, 1-10, 2005.
10. Wilson, D. R., Feikes, J. D., Zavatsky, A. B., and O'Connor, J. J., "The Components of Passive Knee Movement are Coupled to Flexion Angle," *Journal of Biomechanics*, 33, pp. 465-473, 2000.