Introduction: Even though posterior cruciate ligament (PCL) reconstruction has become more popular with the advance of arthroscopic surgical techniques, the most effective arthroscopic PCL method has not been understood [1]. Recently, we reported the clinical outcome of a double bundle PCL augmentation using split Achilles allograft [2]. It is believed that the remnant fibers of the PCL would heal with the graft and could improve the posterior stability of the knee. The purpose of this study was to evaluate the biomechanical efficacy of the double bundle PCL augmentation comparing with those of conventional one and two bundle reconstruction methods by using the finite element analysis.

Materials and Methods: A three-dimensional finite element (FE) model of the healthy lower extremity was developed based on CT images using FEMAP® (EDS Corp., USA, Ver. 8.2). The FE model consisted of femur, tibia, patella, cartilage, meniscus, and four major ligaments. The long bone models included cortical bone, cancellous bone, and canal. The cartilage and the meniscus model were developed based on previous study [4]. The bone, the cartilage, and the meniscus models were assumed as linear elastic. The ligament models were defined as nonlinear springs. The material properties of different bony and soft tissue models were adopted from previous studies (Fig. 1).

For the validation of the intact model, we compared the tibial translations with those in previous study [4] for 100N of anterior and posterior forces. In addition to the intact model, PCL deficient, one bundle and two bundle reconstruction, and double bundle augmentation models were developed based on clinical approach using Achilles allograft. In order to have same total area of the ligaments, 6mm diameter was used for one bundle reconstruction model, 8.5mm diameter was used for two bundle reconstruction and augmentation model, and 12.7 mm and 2.4 mm in [3] and 12.9 mm and 2.8 mm in [3], thus supporting the results of present study. The results of this study showed that the double bundle augmentation model has advantages of rotational stability and ligament stresses, even though the posterior stability in the double bundle augmentation model showed no difference with that in the two bundle reconstruction model. From this finding, we think that the double bundle augmentation method would be beneficial for rotational stability and injury risk of the reconstructed ligament tissue.

Results: For the model validation, tibial translations in our model were close to those in [4]. The double bundle augmentation model showed similar translational stability comparing with the two bundle reconstruction model and higher than the one bundle reconstruction (Fig. 2a). The posterior translation was 2.1mm in the double bundle augmentation model for 90N of posterior drawer test while 2.4mm, 2.2mm, 2.1mm, and 11.9mm for the intact, one bundle, two bundle reconstruction, and pre-operative (PCL deficient) model, respectively. However, for 3 Nm of torsion, the double bundle augmentation model showed 12.1° while the intact, one bundle, and two bundle reconstruction model showed 14.0°, 15.5°, and 13.1°, respectively (Fig. 2b). For the posterior cruciate ligament stresses, the augmentation model has lower stress values compared with other models in 90N of posterior drawer test (Fig. 3). In the augmentation model, the stresses of remnant fibers (Rem) and two reconstructed ligaments (AL and PM) were 0.6MPa, 2.1MPa, and 1.6MPa, respectively, while the stresses in three parts of PCL (anterior part, aPCL; medial part, mPCL; posterior part, pPCL) in intact model were 1.6MPa, 1.6MPa, and 2.9 MPa, respectively, and the stresses in reconstructed ligaments were 4.2MPa (1B) in the one bundle model, and 2.1MPa (2B AL) and 2.2MPa (2B PM) in the two bundle model, respectively.

Discussion: The posterior translations in the pre-operative and augmentation models were 11.9 mm and 2.1 mm, respectively, which were similar to clinical tests; 12.7 mm and 2.4 mm in [2] and 12.9 mm and 2.8 mm in [3], thus supporting the results of present study. The results of this study showed that the double bundle augmentation model has advantages of rotational stability and ligament stresses, even though the posterior stability in the double bundle augmentation model showed no difference with that in the two bundle reconstruction model. From this finding, we think that the double bundle augmentation method would be beneficial for rotational stability and injury risk of the reconstructed ligament tissue.


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