Introduction
The transplantation of autologous cartilage/bone (osteochondral) grafts offers a treatment for full thickness cartilage defects on the femoral condyle of the knee. The cartilage defects may either be post-traumatic or due to an unstable area of osteochondritis dissecans. The osteochondral (OC) grafts are harvested from relatively light-loaded regions, typically the periphery of the non-articulating margin of the femoral condyle, and are inserted into the prepared recipient holes at the site of the defect. It is technically difficult to control precisely the depth alignment of the plug and the amount of press fit in the recipient hole. Inadequate setting of the OC plugs into the pathological site may produce abnormal stress and strain distributions in the joint and influence the repair of the injured cartilage sites [1]. The purpose of the present research was to determine theoretically the influence of press fit and depth alignment of the transplanted plugs on the contact mechanics and the stress and strain distribution within the cartilage of the OC plug and the surrounding regions.

Methods
The joint was assumed to be axi-symmetric with a spherical femur and tibia and a cylindrical OC graft (Fig. 1). The coefficient of friction between plug and recipient hole walls was assumed to vary from 0.1 to 0.5. The recipient hole was taken to be approximately 1.2 mm deeper than the height of the OC plug, so the plug was not resting on the femoral bone. The cartilage was assumed to have a constant thickness of 2 mm and biphasic material properties [2]. Because of the large deformation of cartilage during loading, hyperelastic relations for the solid phase and the deformation-dependent permeability were used in the simulations [3]. Subchondral bone was assumed to be elastic with a much higher elastic modulus than that used for the cartilage. The press fitting was simulated using a thermal analogue. The plug was assumed to have an anisotropic thermal expansion coefficient. Expansion only occurs in the radial direction. Fitting of the plug into the recipient site on the femur was simulated numerically by increasing the temperature of the plug. All simulations were performed in two stages: first, the plug was fitted into the femur and was assumed to experience a thermal expansion; second, the Tibia was displaced by a given amount to produce contact with the femur. Numerical simulations were performed using a displacement-controlled protocol. The femur was fixed, while the Tibia was loaded using a prescribed displacement at a rate of 0.2 mm/s. A commercially available software package ABAQUS (version 5.8) was used in the finite element simulations.

Results
The maximum sliding forces of the OC plugs were estimated by integrating the contact stress between the plug and the recipient hole, and assuming variation in the friction coefficient from 0.1 to 0.5. For a fixed coefficient of friction and a fixed press fit, the maximal sliding force varied with the size of the plug and reached the maximum at a plug diameter of 5.5 mm. Joint stiffness was predicted to decrease as the amount of the plug step increased (i.e., plug step-up), and to increase as the amount of the plug step decreased (i.e., plug step-down). Maximum stiffness was reached at step-down of approximately -0.25 mm. For a fixed size of the plug, the maximal contact stress between tibia and femur/plug was predicted to increase as the amount of the plug step-up increased, and to decrease as the amount of the plug step-up decreased. For the same loading and plug geometry, typical stress and strain fields in the cartilage layers around the implanted OC plug were determined for different step-up and -down conditions (Fig. 2).

Discussion
Inadequate setting of the plug into the pathological site may induce abnormal stress and strain distributions in the joint and interfere with adequate adaptive responses of the femoro-tibial cartilage, possibly delaying or preventing the repair process. Our analyses show that the depth alignment of the plug (step up or down) induces abnormal tension in the tibial cartilage (Fig. 2), which could induce an unknown cartilage adaptation, because cartilage is typically under compression during physiological loading. The contact stress profiles in the joint were predicted to change discontinuously across the plug/femur interface, even when the plug was perfectly flush in the recipient hole. This discontinuity is caused by the material discontinuity in the repaired cartilage surface. The present research is helpful to define design requirements for surgical instruments used for transplantation of osteochondral grafts. It might also provide insight for understanding cartilage adaptations and clinical problems that may be associated with the transplantation of osteochondral grafts.

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References

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