INTRODUCTION
Artificial disc arthroplasty, as a promising treatment for disc degenerative diseases, has been reported to restore normal disc height, preserve segmental motion and decrease adjacent level degeneration. Despite its encouraging short term outcomes, complications related to device and surgical procedure such as subsidence, dislocation and instability due to misalignment warrant further study. Moreover, the attempts to investigate the possible influence of the device design on facet and uncovertebral joint degeneration are rare. Previously, three different artificial disc prostheses, Bryan, Prestige LP (Medtronic Spinal & Biologics, Minneapolis, MN), and ProDisc-C (Synthes, Inc., West Chester, PA) were analyzed in our group using an image based finite element method (FEM) to investigate the propensity of subsidence due to the device design. In this successive study, the load sharing at the facet and uncovertebral joints was estimated by FEM and the difference in the device designs that leads to the presented consequences was also discussed.

MATERIALS AND METHODS
In vivo 3D image based finite element models were built for C5-C6 spine unit from CT images of a patient with indication for arthrodesis (Fig 1). C5-C6 spine unit with prostheses were also prepared by placing three artificial discs into the intervertebral disc space. Facet joints and uncovertebral joints were modeled as hexahedral solid elements for all models. Stress analyses were conducted using Voxelcon (Quint, Inc., Tokyo, Japan) under normal physiological loads in extension and lateral bending with pre-compression (1.5 Nm of moments with 73.6N of pre-compression). The compressive load was implemented by distributed force and moments were implemented by load couples. Inferior of C6 was fixed in all degrees of freedoms. Von Mises stress levels experienced by facet joints and uncovertebral joints were examined among the artificial disc models and the intact model, which evaluated the effect of the prosthesis design on the joint load sharing. In addition, strain energy densities (SED) were calculated to investigate how the prostheses affect the energy transfer pattern at each joint.

RESULTS
Load-displacement response in compression fell in the previous analysis (0.05 mm under 73.6 N). Range of motion (ROM) of intact model in flexion and extension was 2.5 degree, which showed stiff response due to solid FE modeling of facet joints. Thus, facet loads in extension and lateral bending were considered. Fig 2 illustrates the comparison of average strain energy density and average von Mises stress levels at facet joints of C5-C6 spine unit with Bryan, Prestige LP, ProDisc-C and intact model in extension and lateral bending. Facet stress level and SED are highest in the Bryan implanted unit and comparable to that of intact model. Prestige LP implanted model showed lowest stress level due to rigidity of the implant core. In lateral bending, similar trend of facet stress levels were obtained, meaning that core rigidity may determine the load sharing in facet joints. Fig 3 presents SED and von Mises stresses at uncovertebral joints in flexion and lateral bending. Bryan disc transferred much higher energy (0.02 N/mm²) than intact model (0.009 N/mm²) in flexion. In lateral bending, energy density levels at uncovertebral joints in all disc implanted models were at least three times higher than that of intact model. Uncovertebral joint stress levels, especially in lateral bending, were shown to increase after artificial disc implantation (Fig 3 B).

DISCUSSION
Although high mobility of artificial discs may be desirable for the segmental motion preservation, semi-constrained motion may be beneficial to avoid load transmission to facet joints. Bryan disc transmitted similar level of SED and von Mises stresses to posterior facets while providing high mobility with its polyurethane core. However, Bryan disc may have the propensity to increase strain energy and stress at uncovertebral joints, which may increase the incidence of pathological joint degeneration induced by the overload. For Prestige LP and ProDisc-C, facet loads were very small due to rigid cores. Less load levels at facet joints may be referred to less load bearing burdens at the joints, yet it raised another concern for less mechano-stimulation at the joints that may lead to atrophic tissue due to low use or even disuse. It should be noted that Prestige LP and ProDisc-C imposed high SED at uncovertebral joints in lateral bending. This could be explained by the designed endplate edges that impinge into the uncovertebral joint space to elevate the contact stress. In addition, improper placement during surgery may cause even more excessive loads transferred to the joints, which can end up with more mechanical damages. Although the current analysis was restricted to the linear static analysis due to the limitation of the developed tool, the results could still provide valuable information for observing the alteration of the shared loads at facet and uncovertebral joints after the disc arthroplasty with different implants. Future studies will be extended to the nonlinear ligamentous models with facet contact to increase the proximity of the simulation.

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REFERENCES