Biomechanical Efficacies of the Expandable Stand-alone Cages in terms of Stress Distributions and Material Selections

INTRODUCTION:
The lumbar interbody fusion with cage is capable of restoring the instability of spinal segments and maintaining the normal intervertebral space [1]. However, despite its popularity, it has been cited that restoration of the normal lordotic curve of the spine is often difficult due to limited angulation provided by the cage itself. Loss of lordotic curve may lead to undesirable motion behaviors and load bearing characteristics of the post-operative spine [2]. Recently, expandable cages that are capable of producing lordotic curve have been introduced. They are made of either Ti-alloy, polyetheretherketone (PEEK) with excellent biocompatibility and less stiffness, or combination of both [3]. Prior to expansion, it is of rectangular box/cylindrical shape for easy insertion into the intervertebral space. It has a slit in the anterior part which can be expanded to increase the anterior height of the cage generating a certain lordotic angle. Manufacturers contend easy insertion and restoration of normal sagittal lumbar profile [2]. However, biomechanical effects on the structural integrity due to expansion mechanism and material selection still remain largely unknown. In this study, a finite element (FE) was performed to investigate biomechanical behavior of the expandable cage in terms of structural integrity and range of motion at the index and the adjacent levels. In addition, effects of changes in material of the cage and bone graft filling were studied.

METHODS:
A previously-validated 3-dimensional FE model [4] of the intact lumbar spine (L2-S1) was used. For the implanted models, the intact model was altered to simulate the insertion of the cages at L4-5 level after laminectomy and discectomy. The expandable cage used in our study was the posterior lumbar interbody fusion (PLIF) type cage (Varian Expandable Cage, Medyssey Co., Korea) which consists of three parts (body, anterior plate, posterior cap) as shown in Fig. 1. By inserting a turning instrument through the posterior cap and rotating the anterior plate 90° counter-clockwise, its anterior tip can be parted and expanded to produce a lordotic angle of up to 8°. Three types of material selection were considered: Ti-alloy (E=120GPa, v=0.342), Yield strength = 880MPa), PEEK (3.6GPa, 0.3, 110MPa), and the combination of PEEK body wt/ Ti-alloy cap and plate. Three different sequences of the implantation - before and after expansion of the cage, subsequent bone graft (E = 12GPa, v=0.3) filling inside of the void were studied in terms of structural stiffness and motion behaviors. It was assumed that the pre-expanded cage remained as a box type without any slit or openings (i.e., conventional box type cage). Therefore a total of nine kind of cage models were constructed in terms of materials (n=3) and expansion (n=3). These cages were assumed to be inserted bilaterally.

RESULTS:
As expected the peak stresses were found near the anterior tip of the expanded part of the cages in all cases, indicating the location of the weakest element within the cage (Fig. 3). Expansion resulted in sharp increases in peak stresses, especially in PEEK (44% increase) and PEEK+Ti-alloy (155% increase) cages. The peak stress to strength ratio surpassed 1 in PEEK (1.10) and PEEK+Ti-alloy (2.67) cages following the expansion than was reduced to less than 1 (0.37, 0.98) after filling the inside void with bone graft. This suggested that bone graft filling significantly increased structural integrity. However, the PEEK+Ti-alloy case still appears to be vulnerable to fracture with the ratio being close to 1. The highest ratio of 2.67 was noted with the PEEK+Ti-alloy case after expansion, perhaps caused by that mismatch of materials with different stiffness values. Apparently, stresses were higher in flexion than in extension. Expansion led to a slight decrease (by up to 6% in flexion) in motion at the fused level and relatively unchanged at the adjacent level (Fig. 4). ROM was not altered by subsequent bone grafting. Ti-alloy cages resulted in less segmental motions but the changes in motion behavior due to expansion and bone grafting were relatively unchanged regardless of material selection.

DISCUSSION:
Our results demonstrated that the expandable cages can be prone to structural failures due to stress concentration at the tip and materials mismatch even though bone graft filling significantly reduce the peak stresses. Restoration of lordotic angle with expansion mechanism did not contribute much to reduction of adjacent level motions. Therefore, it is suggested more careful selection of materials and design are needed to further improve the biomechanical efficacies of the expandable cages.

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REFERENCES:
[1] Spruit et al., Eur Spine, 2005