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Influences of disc degeneration and bone mineral density on the structural properties of lumbar end plates

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Abstract

BACKGROUND CONTEXT: Implants subsidence is a frequent complication of interbody fusion, which can result in pain, deformity, nerve damage, and even failure of surgery. The end plates as the interface between implants and the vertebral bodies play a very important role in sharing the compression on the vertebral bodies. The information on the structural property distribution of the end plate and its relationship with bone mineral density (BMD) and disc degeneration will be of great significance for the reduction in implants subsidence and improvement in related operative procedures to increase the success rate of interbody fusion.

PURPOSE: To investigate the structural property distribution of the lumbar end plate; the effects of disc degeneration on the biomechanical properties of the lumbar end plate; and the relationship between the biomechanical properties of the lumbar end plate and BMD.

STUDY DESIGN: A biomechanical study was conducted in human cadaveric lumbar spine models.

METHODS: Indentation tests were performed at 24 standardized test sites in 120 bony end plates of intact human vertebrae (L1–L5) using a 1.5-mm–diameter, hemispherical indenter at a speed of 0.2 mm/s. The failure load at each test site was determined using the load-displacement curve. Disc condition was evaluated using a four-point grading scale and bone density was measured using the lateral dual-energy radiograph absorptiometry scans. All end plates were divided into different disc degeneration groups based on the states of the adjacent degenerative discs and BMD groups according to BMD values of the corresponding vertebral bodies. The experimental results were statistically analyzed using the SPSS 15.0 with the disc degeneration and BMD being considered as independent factor, and the failure loads of the superior and inferior end plates were also compared.

RESULTS: The peripheral regions of lumbar end plates were stronger than the central regions ($p<.05$), with the posterolateral sites in front of vertebral pedicles being the strongest regions. The inferior lumbar end plates were found to be stronger than the superior lumbar end plates ($p<.05$). The disc degeneration was negatively correlated with the failure loads of the lumbar end plates ($r_s=-0.563$; $p<.01$). With increasing disc degeneration, the decreases of failure loads were nonuniform across the lumbar end plate, and the central region became weak with little strength change on the end plate periphery. The BMD was positively correlated with the failure loads of the lumbar end plates ($r_s=0.812$; $p<.01$). The failure loads decreased uniformly across the end plate surfaces as the BMD dropped, and the BMD decrease did not change the structural property distributions of lumbar end plates.

CONCLUSIONS: Preoperative evaluation of the states of intervertebral discs and BMD of patients is necessary for predicting risks of implants subsidence after interbody fusion. For patients with or without disc degeneration or osteoporosis, the implants should be placed at the peripheral regions, especially the posterolateral sites, to acquire higher mechanical strength to reduce subsidence as much as possible.

Keywords: Disc degeneration; Bone density; Lumbar end plate; Biomechanical property

FDA device/drug status: Not applicable.

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Introduction

Intervertebral structural support is required after either vertebral body resection or complete disc excision. To provide structural support and maintain biomechanical properties of the anterior column of spine, prosthetic devices and/or structural autografts or allografts are inserted between the remaining vertebrae. One mode of failure for this type of procedure is subsidence, in which the implants or grafts sink into one or both of the vertebrae. Subsidence can be a significant complication leading to deformity, compromise of neural elements, and unfavorable biology resulting in nonunion [1,2]. To prevent implants subsidence, it is important to take advantage of the strongest regions of the end plate, which must have sufficient strength to resist the large in vivo loading [2]. As the interface between the implant and the vertebral bone, the strength of end plate has been reported to be dependent on bone mineral density (BMD) and implant area [2–6]. In these studies, different implant designs were compared, and the minimum graft-bone contact areas to prevent subsidence were recommended. However, these studies did not consider the possibility that the strength of the end plate varies across its surface.

In addition to BMD, degenerative changes in the spine may be also associated with the strength of the end plate, which would have implications for implant design. However, little has been reported by literature about the relationship between biomechanical properties of lumbar end plates and disc degeneration. Keller et al. [7] tested 1-cm cubes of trabecular bone taken from the superior and inferior surfaces of lumbar vertebrae and found that there was regional variation in the strength and stiffness, which changed with disc degeneration. However, the effects of the bony end plate were not addressed in this research. It has been reported that when intervertebral discs degenerate, they have been shown to distribute loads less uniformly over the vertebral end plates [7–11], which may have regional effects on bone remodeling [12]. The distribution of end plate properties may change, reflecting these underlying structural changes.

The primary objective of this study was to investigate effects of disc degeneration on the biomechanical properties of lumbar end plates. In addition, the relationship between BMD and structural property distributions of end plates was also studied. The findings are expected to provide experimental evidence for spine surgeons' reference to improve implants designs, placement, and reduce postoperative graft subsidence as much as possible.

Materials and methods

Specimen preparation

A total of 120 end plates from 12 fresh-frozen human lumbar spines (L1–L5, age 45–89 years, mean 73.8 years) were used in this study, including three women and nine men. Radiographic examination of all specimens were conducted to exclude deformity and tumor, and disc health of spines was evaluated based on the presence or absence of osteophytes, osteoporotic fractures, and decreased disc height. According to the radiographs, the spines represented a wide range of degenerative states, from ''healthy'' (large disc spaces of approximately uniform height, good delineation of vertebrae, no osteophytes, and no osteoporotic fractures) to badly degenerated states (osteophytes, decreased disc height, and/or osteoporotic fractures elsewhere in the spine [not in L1–L5]). According to the radiographs, two spines were considered healthy, five showed evidence of osteoporosis, three presented signs of disc degeneration, and two showed evidence of both disc degeneration and osteoporosis.

The specimens were divided into 60 isolate vertebrae by sectioning the discs through the center using a 7-cm–long saw. The top and bottom half of each disc were photographed using a digital camera (FinePix F30; Fuji Photo Film Corp., Japan) with a micro-distance photography pattern. After discs had been photographed, the end plates were cleaned using a scalpel to remove the disc and cartilage tissue, leaving the bony end plate exposed. A four-point grading scheme established by Nachemson [10] was used to grade the level of disc degeneration based on the evaluation of disc tissue by macroscopic inspection (Table 1). Both disc halves were used together to grade the discs from L1 to L5, and only the lower half was used to grade the T12–L1 and L5–S1 discs. Because of the

Table 1
Classification of macroscopic patho-anatomic changes associated with disc degeneration according to Nachemson [10]

Degenerative disc disease assessed by macroscopic inspection	
Grade of degeneration	
A	Discs without changes visible to the naked eye. In these cases, a gelatinous shiny nucleus pulposus was seen; it was easily delimited from the annulus fibrosus, which was free from macroscopic ruptures.
B	Discs that showed macroscopic changes in the nucleus pulposus. The nucleus was somewhat more fibrous, but could be clearly distinguished from the annulus, which was intact
C	Specimens that showed macroscopic changes in both the nucleus pulposus and the annulus fibrosus. The nucleus in these discs was more fibrotic but still soft. The boundary between nucleus and annulus was no longer so distinct, but could be seen. Changes in the annulus fibrosus consisted of isolated fissures
D	Specimens that showed more severe macroscopic changes. The disc in this group exhibited fissure formation and cavities in both the nucleus and the annulus. Marginal osteophytes were often found in adjoining vertebrae