Eklem Hastalıkları ve Cerrahisi
Joint Diseases and Related Surgery

Experimental Study / ***Deneysel Çalışma***

Eklem Hastalık Cerrahisi
2013;24(1):33-38
doi: 10.5606/ehc.2013.08

Biomechanical comparison of intact lumbar lamb spine and endoscopic discectomized lamb spine

Sağlam kuzu omurgası ile endoskopik diskektomi yapılmış kuzu omurgasının biyomekanik olarak karşılaştırılması

Ahmet Karakaşlı, M.D.,[1] Didem Venüs Yıldız, M.Sc.,[2] Erdem Kumtepe,[3]
Ceren Kızmazoğlu, M.D.,[4] Hasan Havıtçıoğlu, M.D.[5]

[1]Department of Orthopedics and Traumatology, Tire State Hospital, İzmir, Turkey
[2, 3]Department of Biomechanics, Institute of Health Science, University of Dokuz Eylül, İzmir, Turkey
[4]Department of Neurosurgery, Medical Faculty of Dokuz Eylül University, İzmir, Turkey
[5]Department of Orthopedics and Traumatology, Medical Faculty of Dokuz Eylül University, İzmir, Turkey

Objectives: This study aims to perform a biomechanical comparison of changes on motion segments after minimally invasive percutaneous endoscopically discectomized and intact spine and to investigate the effects of endoscopic discectomy on the lumbar spine of the lamb.

Materials and methods: Ten fresh-frozen lamb spines were used in this study. Percutaneous endoscopic discectomy was performed on each spine at L4-L5 level. The biomechanical tests for both intact spine and endoscopically discectomized spine were performed by using axial compression testing machine. The axial compression was applied to all specimens with a loading speed of 5 mm/min. 8400 N/mm moment was applied to each specimen to achieve flexion and extension motions, right and left bending through a specially designed fixture.

Results: In axial compression and flexion tests, the specimens were more stable based on displacement values. The displacement values of discected spines were closer to the values of intact specimens. Comparing both groups, only displacement values of the left-bending anteroposterior test were significant ($p \leq 0.05$).

Conclusion: Percutaneous transforaminal endoscopic discectomy (PTED) has no biomechanical and clinical disadvantages. Endoscopic discectomy has also no stability disadvantages. Only anteroposterior displacement values of left bending test were statistically significant. We consider that the reason for such results were due to the fact that PTED was performed on the left side of all specimens.

Key words: Biomechanics; endoscopic discectomy; intact spine.

Amaç: Bu çalışmada minimal invaziv perkütan endoskopik diskektomi sonrası omurganın hareketli segmentinin biyomekanik değişiklikleri sağlam omurga ile karşılaştırıldı ve endoskopik diskektominin lomber kuzu omurgası üzerindeki etkileri araştırıldı.

Gereç ve yöntemler: Bu çalışmada 10 adet taze donmuş kuzu omurgası kullanıldı. Her bir omurgaya L4-L5 seviyesinde perkütan endoskopik diskektomi yapıldı. Sağlam ve endoskopik diskektomi yapılmış omurgalar için biyomekanik test, aksiyel kompresyon test makinesi kullanılarak gerçekleştirildi. Aksiyel kompresyon tüm örneklere 5 mm/dk yükleme hızı ile uygulandı. Her bir omurgaya, özel tasarlanmış bir aparatla, 8400 N/mm moment fleksiyon, ekstansiyon, sağa eğilme ve sola eğilme hareketlerinde uygulandı.

Bulgular: Aksiyel kompresyon ve fleksiyon testlerinde yer değiştirme bulgularına göre örnekler daha stabildi. Diskektomi yapılmış omurgaların yer değiştirme değerleri, sağlam omurgaların değerlerine yakındı. Her iki grup karşılaştırıldığında, sadece sola eğilme ön-arka kayma değerleri anlamlı idi ($p \leq 0.05$).

Sonuç: Perkütan transforaminal endoskopik diskektominin, (PTED) biyomekanik ve klinik açıdan dezavantajı yoktur. Endoskopik diskektominin stabilite yönünden de herhangi bir dezavantajı yoktur. Yalnızca sola eğilmede öne arkaya kayma değerleri istatistiksel olarak anlamlı bulundu. Bu sonuçların nedenini tüm omurgaların sol taraftan PTED yapılmış olmasına bağlamaktayız.

Anahtar sözcükler: Biyomekanik; endoskopik diskektomi; sağlam omurga.

- *Received: September 24, 2012 Accepted: December 11, 2012*

- Correspondence: Ahmet Karakaşlı, M.D. Tire Devlet Hastanesi Ortopedi ve Travmatoloji Kliniği, 35900 Tire, İzmir, Turkey.
Tel: +90 532 - 325 10 32 Fax: +90 232 - 511 21 99 e-mail: akarakasli@mail.city.com

Lumbar discogenic radicular pain secondary to lumbar disc prolapse, protrusion, or herniation accounts for less than 5% of low back problems.[1] The intervertebral disc, in accordance with its mechanical requirements, is an organized, independent cell unit. One of its main functions consists of dampening compressive loads.[2] It functions in contributing to load bearing, impact absorption, and stress transmission between the vertebrae. During physiologic activities, the intervertebral discs are exposed to various and complex mechanical loadings.[3]

Lumbar discectomies are often performed to decompress the nerve root and alleviate radicular pain in cases of failed conservative therapy. The primary goal of surgical treatment is the relief of nerve root compression by removing the herniated nuclear material and the primary modality of treatment has been open discectomy. Surgical success in treatment of spinal deformities depends on several factors such as approach (anterior/posterior/both) and release techniques.[4] Extruded and sequestered disc herniations may require more invasive procedures to retrieve the disc material, whereas disc protrusions are potentially more amenable to minimally invasive percutaneous procedures.[5] The full-endoscopic transforaminal operation with posterolateral access evolved out of this.[6] The technique of percutaneous endoscopic transforaminal lumbar discectomy (PTED) has evolved over the years and is increasingly becoming a preferred choice of treatment for the management of lumbar disc herniation. The PTED, by virtue of its transforaminal approach, offers several advantages over open methods like protection of posterior ligamentous and bony structures, less postoperative instability, facet arthropathy, and disc space narrowing. Also, there is no interference with the epidural venous system that may lead to chronic neural edema and fibrosis.[7]

Many authors think that the stability of spine is preserved because the anatomical components of the spine are not damaged after PTED. However, careful review of the literature revealed no adequate biomechanical study on PTED. Thus, we conducted the present study focused on a biomechanical comparison of the changes wrought on motion segments after a minimally invasive endoscopic discectomy and intact spine. We aim to prove that PTED does not result in any instability in the aspect of biomechanics.

MATERIALS AND METHODS

Specimens

Ten fresh-frozen lamb spines were used for this study. The ages of the lambs were six-twelve months. The specimens were free of macroscopic and radiological diseases. The spine of each specimen was dissected from the sacrum to T_{12} level. All of the specimens were frozen and thawed at room temperature one night before tests.

Surgical Method

All specimens were bluntly fenestrated with an obturator from the disc annulus of L4-L5 on the left side. A 7 mm beveled cannula was then advanced over the obturator and docked within the annular fibers. The obturator typically entered the disc at a 25 to 35 degree angle in relation to the coronal plane and was parallel to the end plates. The obturator was removed and replaced by the operating endoscope. The endoscopic rongeurs were inserted down the working channel of the endoscope and the microdiscectomy operation was carried out.[5,6]

Biomechanical tests

The study was conducted in the Biomechanics Laboratory, Institute of Health Sciences, University of Dokuz Eylül. The biomechanical tests were performed using the axial compression testing machine (AG-I 10 kN, Shimadzu, Japan). The test device had data processing software TRAPEZIUM2 and CCD camera extensometers (Non-contact Video Extensometer DVE-101/201, Shimadzu, Japan) which were the elongation meters that enabled elongation measurement without making contact with the test specimen. In the current study, at first phase, 400 Newton (N) axial loads were applied to intact spine in neutral position and 8400 Nmm moments were applied to intact spine in flexion and extension motions, and right and left bending positions. The current study was conducted in two groups. The spines were load tested in the following sequence: 1) Load testing of the intact spine before any manipulation. 2) Load testing after PLED of spine from L4-L5. In the axial neutral position 400 N axial compression loads were applied to each specimen in both groups (Figure 1). A specially designed fixture used to increase moment up to 8400 Nmm generated through the axial movement of the actuator was applied to each specimen to achieve the flexion and extension motions, right and left bending respectively (Figure 1).[8] During the biomechanical test period, intervertebral displacement at decompression levels L4-L5 was recorded continuously by the extensometer. While preparing test specimens, suitable gauge marks (diamond mark for high accuracy) were selected for the test specimen. Gauge marks were applied to test specimens with pins due to the sliding surfaces of the specimens. Gauge marks were attached to L4 and L5 to measure the superior-inferior and anterior-posterior

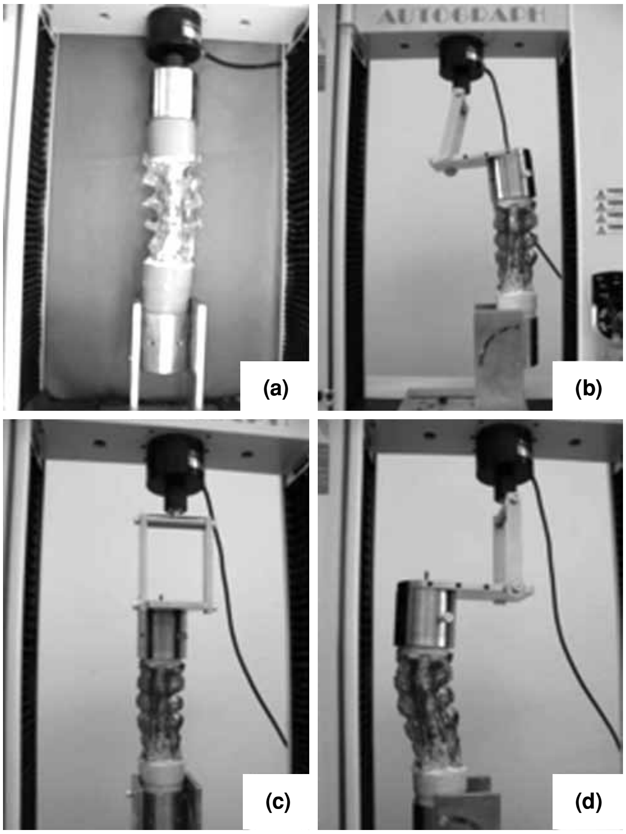

Figure 1. Various positions in biomechanical test. **(a)** Axial compression test. **(b)** Right bending test. **(c)** Flexion test **(d)** Left bending test.

displacement. The two non-contact cameras captured images of the gauge marks. A personal computer processed the gray-scale image and measured displacement of the gauge marks of each camera image to measure the elongation of the test specimens. The gauge mark displacement on the CCD screen was converted into actual displacement. The displacement values were recorded on a personal computer connected with the test machine and two non-contact cameras. The data of displacement values was evaluated with Wilcoxon signed rank test by software SPSS (SPSS Inc., Chicago, Illinois, USA) version 15.0 for Windows. The study was planned and documented as recommended by Atik.[9]

RESULTS

Resultant displacement median values of the biomechanical study are shown in Table I. Median displacement values of intact spine of 10 specimens for each position of axial compression test, compression test in flexion, extension motions and right, left bending positions in intact specimens were 3.64 mm, 6.73 mm, 1.07 mm, 3.37 mm and 2.37 mm respectively (Figure 2). After endoscopic discectomy for each lamb spine median values of measurement results of current biomechanical study are shown in Table I. Median displacement values of discectomy lamb spines of each specimen for each position of axial compression test, compression test in flexion, extension motions and right, left bending positions were 3.76 mm, 6.69 mm, 1.34 mm, 4.76 mm, 3.01 mm respectively (Figure 2). Displacement results for two phases of this study were compared statistically. A significant change was found between displacement values of specimens under compression only in left bending position (p=0.047). There were no statistically significant changes in position of axial compression test, compression test in flexion, extension motions and right bending position for both groups.

DISCUSSION

Each spinal segment consists of an anteriorly situated intervertebral disc and small, paired, posterior synovial joints (facet joints) comprising a "three-joint complex".[10] Discectomy (or nucleotomy) in animal models and human cadaver studies demonstrates changes similar to those that occur in early human disc degeneration.[11] The physiologic disc exhibits a clear convex inner and outer annular bulge under loading, both in the anterior and posterior regions.[12]

TABLE I

Median values of displacement results (mm) for intact Lumbar Spine Test and endoscopic discectomized Lumbar Lamb Spine test

	Axial	Axial transverse	Extension	Extension transverse	Flexion	Flexion transverse	Right bending	Right bending transverse	Left bending	Left bending transverse
Median values (n=10) of intact Lumbar Lamb Spine test	3.64	3.85	1.39	6.73	4.27	1.07	1.62	3.37	2.61	2.37
Median values (n=10) of endoscopic discectomized Lumbar Lamb Spine test	3.76	2.25	1.59	6.69	3.57	1.34	2.84	4.76	1.45	3.01

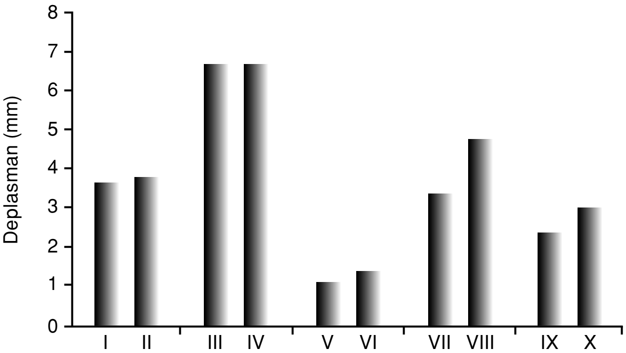

Figure 2. Median values of displacement results of biomechanical tests in various positions. **I.** axial compression test in intact specimens. **II.** axial compression test in endoscopic discectomized specimens. **III.** compression test in flexion motion in intact specimens **IV.** compression test in flexion motion in endoscopic discectomized specimens **V.** compression test in extension motion in intact specimens **VI.** compression test in extension motion in endoscopic discectomized specimens **VII.** compression test in right bending position in intact specimens **VIII.** compression test in right bending position in endoscopic discectomized specimens. **IX.** compression test in left bending position in intact specimens. **X.** compression test in left bending position in endoscopic discectomized specimens.

In our study, because only fragmentectomy is performed in PTED, the disc height was preserved. The displacement values in this study did not show any changes during axial loading compared to intact spine. There were no statistically significant changes during axial loading in both groups.

The annulus fibrosus and nucleus pulposus have distinctly different anatomical morphology, biochemical composition, and biomechanical characteristics.[13,14] It is the unique interaction between the solid matrix and interstitial fluid, which provides the disc with the strength and flexibility necessary to withstand the large motions the spine undergoes during even normal daily activities.[15]

The kinematics and load-deformation relationships of the spine were minimally altered after microdiscectomy. Small increases occurred in ROM, and lateral bending flexibility. Hence, microdiscectomy does not overtly destabilize the spine.[16]

Our study was conducted *in vitro*. After PTED *in vivo* and *in vitro* biomechanical effects cannot be documented. However, we can document *in vitro* biomechanical changes. A small window is opened and only the disc fragment is removed in annulus fibrosis after PTED. A significant statistical instability was observed with 4.45 mm displacement values anterior-posterior direction under left bending load. In all the specimens PTED was performed on the left side. Therefore, in our opinion, there was a significant (p=0.047) change in anterior-posterior displacement during left bending.

After open discectomy at L4-L5 and L5-S1, additional signs of movement (3.94 mm anteroposteriorly and 2.5 mm vertically) were found at L4-L5. A notably large increase in vertical motion (2.98 mm) was seen at L5-S1.[17]

Percutaneous endoscopic transforaminal lumbar discectomy, by virtue of its transforaminal approach, offers several advantages over open methods including protection of posterior ligamentous and bony structures, lesser postoperative instability, facet arthropathy, and disc space narrowing. Also, there is no interference with the epidural venous system that may lead to chronic neural edema and fibrosis.[7,18,19] Percutaneous endoscopic transforaminal lumbar discectomy is a minimally invasive procedure that preserves the stabilizing elements of the spine and avoids epidural scar formation.[6,20]

In this study, the displacement values measured under loading after PTED and on the intact spine were similar to each other. There was no serious damage to the disc following PTED. At the same time, because there was no damage to the posterior components, the displacement values measured were similar to those of the intact spine, except for the anteroposterior displacement values of PTED side bending.

Lu et al.[17] showed that the motions in direction of x (anteroposterial translation) showed no statistically significant difference between the intact and surgically managed states, except at L4-L5. In the direction of y (vertical translation), the motions after different levels of surgery increased significantly at the L4-L5 and L5-S1 segments. Under combined shear and flexion loads, the translations in anteroposterior directions ranged from 3 to 4 mm. In vertical direction, the absolute range of motion was always less than 3 mm, even with significant increases after open surgery. In position of lateral bending, the motions in each segment increased after fenestration and discectomy.[17]

The denucleated disc showed a lower intradiscal pressure (IDP) than the normal disc.[21] Nucleotomy alters the magnitude of radial and axial AF strains. Increased strains may make the AF vulnerable to fatigue damage.[22] The outer AF bulge was not altered by nucleotomy. The extensive nucleotomy by fenestration of the AF resulted in early and severe disc degeneration with considerable endplate damage.[23]

In our study only anterior-posterior displacement values of the left bending test were statistically significant. We consider that the cause of these results was the fact that all the specimens had PTED from the left side. Percutaneous endoscopic transforaminal lumbar discectomy has biomechanical and clinical advantages.

It still has some disadvantages; safe and effective access is limited to a narrow channel and there is little or no working space, as compared with conventional open surgery.[24,25] The limitation of this study was that the effects of surrounding musculature and soft tissues were not taken into account.[26] Another limitation was that the specimens did not have living tissue, as the study was conducted *ex vivo*.

Although efforts have been made to simulate clinical conditions, there are certain limitations to this study. Under laboratory environment, this experimental study used lamb lumbar spines instead of human cadaveric spines. Physiological structures such as spinal alignment and number of lumbar segments of the lamb spines differ from those of human cadaveric spines; however, animal spines are the most convenient choice to perform the experiment with long spinal segments in circumstances where human cadaveric spines cannot be accessed. Investigation on the effects of other loading conditions such as axial rotation might be necessary in the future.

In conclusion, only anterior-posterior displacement values of the left bending test were statistically significant. Percutaneous transforaminal endoscopic discectomy has no disadvantages in the aspects of biomechanics and clinic. Understanding biomechanical instability of the spine in PTED may shed light on choice of surgical techniques and indications for surgery.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

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