THE INFLUENCE OF AUTOMATED PERCUTANEOUS LUMBAR DISCECTOMY (APLD) ON THE BIOMECHANICS OF THE LUMBAR INTERVERTEBRAL DISC AN EXPERIMENTAL STUDY

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Twenty human lumbar motion segments were prepared and tested in an electromechanical materials testing machine in order to investigate the biomechanical changes, i.e. intradiscal pressure, radial extension and height of the intervertebral disc, after automated percutaneous lumbar discectomy (APLD) developed by Onik. The biomechanical data were statistically analyzed with the Friedman test (significance level $p < 0.05$). The APLD lasted 45 minutes in every segment. The mean weight of material removed was 4.6 g. The removal of 4.6 gram of nucleus pulposus material reduced the height of the disc by an average of 1.42 mm. The intradiscal pressure also decreased by an average of 5.7 bar. The radial bulge increased by an average of 0.45 mm.

Our results show that the mechanism improving radicular pain in patients with herniated disc after treatment with percutaneous nucleotomy is still in question. While clinical studies show an improvement of 70% to 85% of patients treated with APLD for herniated disc, this in vitro study showed clearly that radial bulge increases after removal of nuclear material. We postulate that loss of height of the disc and, as a consequence, reduction of tension in the affected nerve root, plays a major role with regard to this improvement.

Keywords : automated percutaneous lumbar discectomy ; biomechanics ; radicular syndrome.

Mots-clés : discectomie percutanée lombaire automatisée ; biomécanique ; syndrome radiculaire.

INTRODUCTION

In 1963 Smith (20) for the first time described the treatment of patients with a herniated disc using the proteolytic enzyme chymopapain. The application of this enzyme was performed by a percutaneous approach. Because of major complications, such as anaphylaxis (6) and transverse myelitis (22), chemonucleolysis became less popular in the mid-seventies. However chemonucleolysis paved the way for other percutaneous treatment modalities. In 1975 Hijikata *et al.* (9) published the non-automated percutaneous lumbar discectomy (NAPLD). Onik *et al.* (15, 16) in 1985 described their technique, the automated percutaneous lumbar discectomy (APLD), for the removal of nuclear material percutaneously. Since 1985, many clinical results of APLD have been published (4, 5, 15, 16, 17), but data about the biomechanical changes of the intervertebral disc caused by this modality are rare. Brinckmann and Grootenboer (3) reported that removal of 1 g of disc tissue by NAPLD resulted in a height decrease of 0.8 mm and a radial bulge increase of 0.2 mm.

Comparing APLD with NAPLD, Pfeiffer and coworkers (18) found that intradiscal pressure decreased down to zero after perforation of the anulus fibrosus. They did not examine the changes in radial bulge and height of the disc after removal of nuclear material. No other publications on biomechanical data of in vitro experiments could be found. In an in vitro study the changes in the height of the intervertebral disc, intradiscal pres-

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sure and radial bulge were investigated in 20 discs of human specimens using the APLD technique.

MATERIALS AND METHODS

Specimens of 8 human lumbar spines (including 35 motion segments) were obtained after autopsy. The time interval between death and autopsy was 12 to 48 hours. The data on the specimens are listed in table I.

Table I. — Data of the human specimens of the lumbar spine

number	sex	age	cause of death
1	female	67 Y.	tumor disease
2	female	76 Y.	decompensation cordis
3	male	57 Y.	respiratory insuff.
4	female	69 Y.	decompensation cordis
5	female	53 Y.	acute heartattack
6	male	64 Y.	tumor disease
7	female	49 Y.	hemorrhagic shock
8	male	49 Y.	tumor disease

The specimens were stored in vacuum-sealed plastic bags at a temperature of −25°C. Nachemson (13) observed no negative biomechanical effects on human discs stored at this temperature. With the use of magnetic resonance imaging (MRI) 20 motion segments out of the total of 35 were selected (six motion segments of the level L2/3, five of the level L3/4 and L4/5 and four motion segments of L5/S1). The segments had to have normal discs, i.e. a normal height of the intervertebral disc and normal signal intensity of the disc as compared with those of a mature spine of a young healthy person. After the MRI examination the posterior elements and the paraspinal musculature were removed. Care was taken not to damage the ligaments between the vertebral bodies. Afterwards, each segment was fixed with bone cement in an electromechanical materials testing machine (fig. 1). The fixation of both ends of the segment as well as the transverse plane through the disc were parallel to each other. In this way, the direction of the axial load was perpendicular to the transverse plane of the disc. Flexion, extension and lateral bending could not take place and shearing could be avoided. The experimental setup to measure the height of the disc and the radial bulge as well as the intradiscal pressure was identical to that used by Brinckmann and Grootenboer (3). The change in height was measured optoelectronically by the electromechanical materials testing machine with an error of 0.01 mm. The radial extension of the disc was measured around its entire circumference by means of a small probe coupled to three electrical transducers (fig. 2). This resulted in a disc contour drawing on the connected computer. The difference in disc contour after each removal of nuclear material could be determined consecutively (fig. 3). The intradiscal pressure was measured by a semiconductor pressure transducer. The only difference in experimental setup was that Brinckmann and Grootenboer (3) performed their experiments at room temperature, while we used 100%-humidified air at a temperature of 37°C, blown into a cage (fig. 4). This cage was placed around the dissected motion segment.

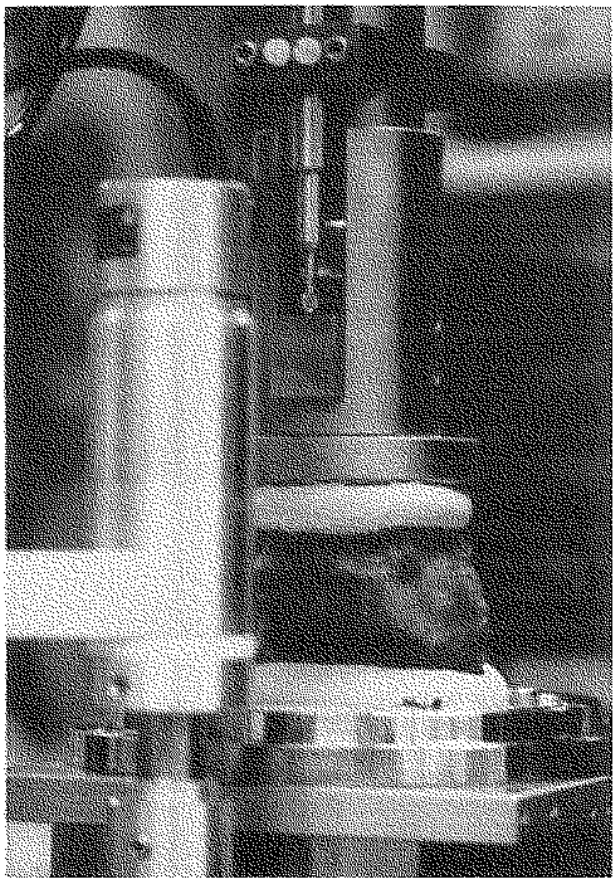

Fig. 1. — A motion segment fixed in the electromechanical materials testing machine. The planes of the ends of the segment in the bone cement as well as the transverse plane of the disc are parallel to each other. (With permission of Enke Verlag, Z. Orthop., 1992).

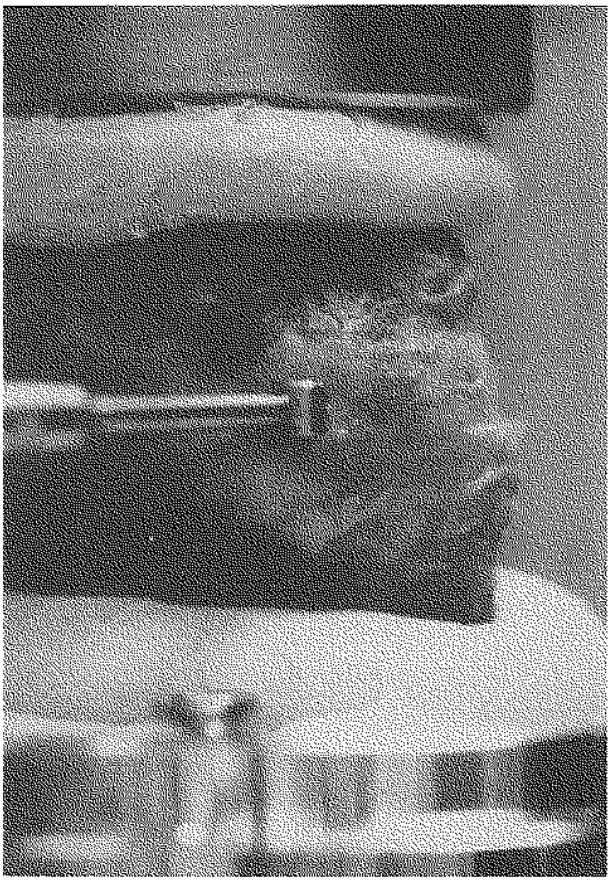

Fig. 2. — The radial extension of the disc is measured around its whole circumference by means of this probe. (With permission of Enke Verlag, Z. Orthop., 1992).

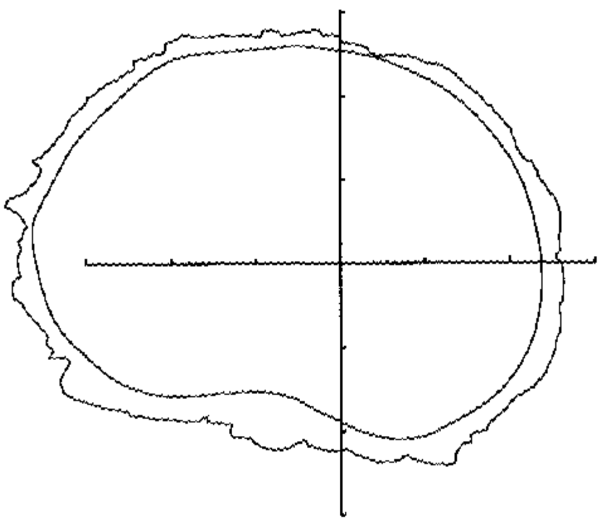

Fig. 3. — Change of the contour of the disc after the removal of nuclear tissue by APLD. The inner contour is the contour measured before the removal. Magnified by a factor of 10 is the difference between both contours in radial direction.

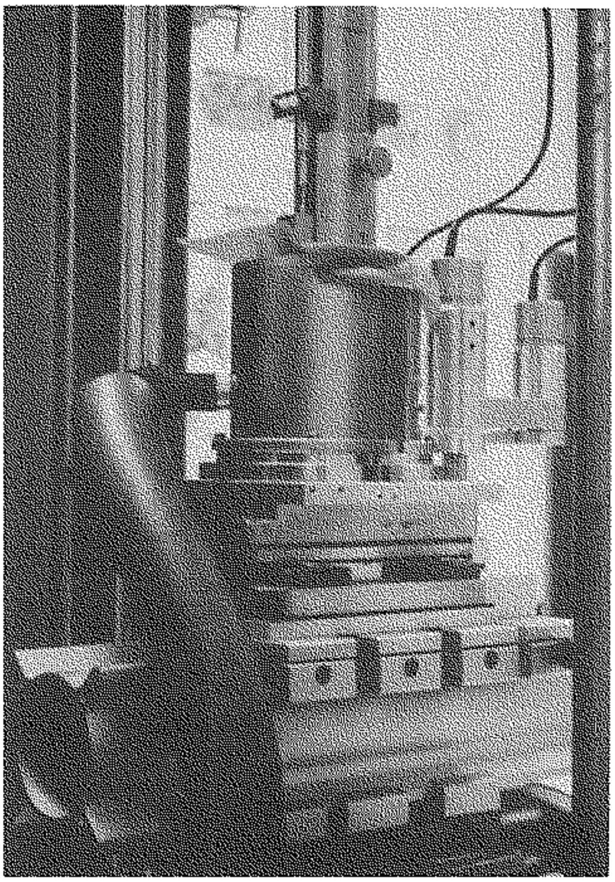

Fig. 4. — 100%-humified air with a temperature of 37°C is blown through the tube into this cage, which is placed around the prepared motion segment. (With permission of Enke Verlag, Z. Orthop., 1992).

Nuclear material was removed using the automated percutaneous lumbar discectomy instruments of Onik (15, 16). The changes in the three parameters, as well as the weight of the extracted wet material, were measured after every 15 minutes of disc material removal. The APLD was performed for 45 minutes in each segment. The measurements of biomechanical parameters were carried out under an axial load of 1000 N, while nuclear material was removed under an axial load of 500 N. This was done in accordance with the experimental work of Nachemson (13) on axial load.

The protocol for performing each experiment on a motion segment was as follows :

— Placement of the motion segment under an axial load of 1000 N for 30 minutes. This was done to adapt the specimen to the 37° C temperature and to reproduce the in vivo axial load.

— Measurement of the loss of disc height after the 30 minutes.

— Measurement of disc contour and intradiscal pressure under an axial load of 1000 N.

— APLD, posterolateral approach ; removal of nuclear material during 15, 30 and 45 minutes under an axial load of 500 N. Measurement of loss of height, radial bulge and intradiscal pressure after every 15 minutes of disc material removal under an axial load of 1000 N.

Measurement of the weight of the removed wet material every 15 minutes.

— All the data were statistically analyzed using the Friedman test. The level of significance was $p < 0.05$.

RESULTS

The height of the disc decreased by an average of 0.47 mm (S.D. ± 0.23) per 15 minutes. In the first 15 minutes the height decreased by an average of 0.73 mm ; in the second 15 minutes, 0.40 mm and in the last 15 minutes 0.30 mm. The differences in loss of height after each 15 minutes were statistically significant ($p < 0.0001$).

Radial bulge increases by 0.45 mm (S.D. ± 0.37) after 45 minutes APLD. Statistics showed that only the difference between the first 15 minutes and the last 15 minutes was significant ($p < 0.05$). On average radial bulge increased after the first 15 minutes by 0.23 mm ; 0.14 mm after the second 15 minutes and 0.08 mm after the last 15 minutes.

The intradiscal pressure significantly reduced by an average of 5.7 bar (S.D. ± 3.8) after 45 minutes of APLD. Statistics showed also that only the difference between the first 15 minutes and the last 15 minutes was significant ($p < 0.05$).

An average of 4.6 g (S.D. ± 2.7) of nuclear material was excised during the 45 minutes of APLD, with the following average distributions : after the first 15 minutes, 2.9 grams (S.D. ± 1.4) ; after the second 15 minutes, 1.1 g (S.D. ± 0.6) and after the third 15 minutes, 0.6 g (S.D. ± 0.6). The differences between the first and second 15 minutes and between the first and the third 15 minutes were statistically significant ($p < 0.05$).

DISCUSSION

Until Smith (20) introduced chemonucleolysis, surgery was the treatment of choice once conservative therapy had failed in patients wth a herniated disc. Besides the risk of developing a failed back syndrome, the complication rate of this operative therapy varied between 2% and 14% (14, 21). At first, chemonucleolysis was thought to be a harmless invasive treatment, but anaphylaxis (6) and transverse myelitis (22) emerged as major complications. Furthermore, 25% of the patients treated by chemonucleolysis had to undergo surgery because of a persistent or recurrent radicular syndrome (1). Therefore the enthusiasm for chemonucleolysis decreased. Other percutaneous methods to treat patients with herniated discs attracted increasing attention. Many clinical studies are reported in the literature (4, 5, 9, 10, 11, 15, 16, 17). In contrast, biomechanical data on the changes caused by these techniques are rare. To our knowledge only two in vitro experiments have been reported (3, 18). Besides these, Goel and Kim investigated biomechanical characteristics of the disc after nucleotomy using the finite element technique (8). They found a reduction of the height of the disc as well as a reduction of the radial bulge.

In our study the biomechanical characteristics of the disc after APLD have been documented. The limiting factor in this study is the fact that all the experiments were performed on lumbar discs with a normal appearance on magnetic resonance imaging. However, until now herniated lumbar discs have not been available for experimental work of this kind. The advantage of the MRI-examination before the experiments is that discs with almost the same morphology could be selected for this study. As a result the value of the results is increased because of this uniformity.

In contrast to the work of Goel and Kim, the most striking result in our study is the increase in the radial bulge. This result is in comparison with the clinical study of Jantea *et al.* (12), who in an MRI study found that the size of the herniated disc did not change significantly after APLD. These facts raise the question : what mechanism causes the improvement in the patients' symptoms after treatment with percutaneous nucleotomy in spite of the increase in the radial bulge ? A possible explanation for this phenomenon was discussed by Falconer and coworkers (7) and by Breig and Marions (2) reporting on the biomechanics of the lumbosacral nerve roots. They found that an increase in the tension in the affected nerve root is a significant factor for the development of sciatica. Spencer and coworkers (19) confirmed the conclusion of Breig and Marions using a mechanical model analysis. They found that narrowing of the disc space significantly reduced the pressure on the nerve root produced by a disc protrusion. As a consequence the tension in the affected nerve root decreases. Combining these known facts from the literature and the results of our study we postulate that although the radial bulge increase, which might lead to an increase of nerve root tension independently, the concomitant decrease in height causes a greater reduction in tension. However, further research must be done to prove this hypothesis.

CONCLUSION

This study was designed to investigate the biomechanical changes after automated percutaneous lumbar discectomy. With an increasing amount of nuclear material excised, the height of the disc space as well as the intradiscal pressure decreases, while the radial bulge increases. The authors postulate that the loss of height of the intervertebral disc plays an important role in the improvement of the radicular syndrome in patients with herniated disc treated by APLD.

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SAMENVATTING

W. H. M. CASTRO, H. HALM en J. RONDHUIS. De invloed van de geautomatiseerde perkutane lumbale discectomie op de biomechanica van de tussenwervelschijf.

Twintig humane lumbale bewegingssegmenten werden geprepareerd en vervolgens getest in een electromechanische materiaal test machine. De biomechanische veranderingen met betrekking tot de intradiskale druk, radiaire uitbreiding en hoogte van de tussenwervelschijf werden na de geautomatiseerde perkutane lumbale discectomie techniek volgens Onik (APLD) bepaald. De biomechanische gegevens werden statistisch geanalyseerd met behulp van de Friedman test (signifikant niveau $p < 0{,}05$). De APLD duurde 45 minuten voor elk segment. Het gemiddelde verwijderde nucleus gewicht bedroeg 4,6 gram. Dit leidde tot een reduktie van de hoogte van de tussenwervelschijf van gemiddeld 1,42 mm. De intradiskale druk nam gemiddeld 5,7 bar af. De radiaire uitbreiding nam gemiddeld 0,45 mm toe. Onze resultaten tonen dat het mechanisme voor de verbetering van de radikulaire pijnklachten bij patiënten met een hernia nuclei pulposus na behandeling door middel van de perkutane nukleotomie nog steeds niet duidelijk is. Terwijl klinische studies een verbetering van 70% tot 85% van deze klachten beschrijven, toont deze in vitro studie dat de radiaire uitbreiding van de tussenwervelschijf toeneemt na het verwijderen van nucleusweefsel. Wij postuleren dat de afname van de hoogte van de tussenwervelschijf, met als gevolg een reduktie van de spanning in de betroffen lumbale zenuwwortel, een belangrijke rol speelt met betrekking tot deze verbetering.

RÉSUMÉ

W. H. M. CASTRO, H. HALM et J. RONDHUIS. Influence de la discectomie lombaire percutanée automatisée sur la biomécanique du disque intervertébral.

Vingt segments mobiles de colonne lombaire furent préparés et testés dans une machine électromécanique, testant les matériaux. Les modifications biomécaniques, notamment la pression intradiscale, l'expansion radiaire et la hauteur du disque furent déterminées après discectomie percutanée lombaire automatisée, suivant la technique d'Onik (APLD). Les données biomécaniques furent analysées en statistique, par tests de Friedman (niveau de signification $p < 0{,}05$). La discectomie percutanée dura 45 minutes pour chaque segment. En moyenne, 4,6 g de tissu nucléaire furent extraits. La réduction subséquente de hauteur du disque fut en moyenne de 1,42 mm. La diminution de pression intradiscale fut en moyenne de 1,7 bar. Le diamètre du disque augmenta en moyenne de 0,45 mm.
Nos résultats montrent que le mécanisme d'amélioration des douleurs radiculaires après nucléotomie percutanée chez les patients présentant une hernie discale n'est pas évident. Alors que les études cliniques établissent une amélioration subjective dans 70 à 85% des cas, cette étude in vitro établit que la largeur du disque augmente après extraction du tissu nucléaire. Nous postulons que la diminution de hauteur du disque qui entraîne une réduction de tension dans la racine lombaire concernée, joue un rôle important dans l'amélioration des plaintes.