10 and null in 2. No complication was observed. Clinical failures were observed in 8 of the 41 patients who had a good filling of the herniation. In contrast, 9 of the 12 patients with a poor or null filling obtained good results. Seven patients had post chymopapain surgery. Non sequestrated herniations associated in 3 patients to a lateral stenosis were found.

DISCUSSION AND CONCLUSION

A high rate of discrepancy was observed between the successful use of chemonucleolysis and the disco CT picture. If the indications of chemonucleolysis had been based on CT discography, 41 chymopapain injections would have been performed with 8 failures. Nine patients who had a successful result would not have undergone the procedure. From these data we do not recommend disco CT as a screening procedure for chemonucleolysis.

AN EXPERIMENTAL STUDY COMPARING PERCUTANEOUS DISCECTOMY WITH CHEMONUCLEOLYSIS, R. Gunzburg, R.D. Fraser, R. Moore, B. Vernon-Roberts. Royal Adelaide Hospital and the Institute of Medical and Veterinary Science, Adelaide, South Australia.

The aim of this study was to assess the macroscopic and microscopic reaction of the intervertebral disc to discectomy with the Automated Nucleotome, and to compare this with simple trephining of the annulus and with chemonucleolysis.

The lumbar spines of twelve adult merino wethers sheep were exposed through left sided retro-peritoneal muscle splitting approaches. In eight sheep, two of four adjacent lumbar discs were randomly incised using the trephine of the Automated Nucleotome, while the remaining levels underwent nuclear excision with the Automated Nucleotome probe. In another four sheep reconstituted chymopapain was injected at three adjacent lumbar levels. Six weeks after surgery the animals were killed and the lumbar spines were removed. After fixation in formal saline the spines were divided in the sagittal plane and examined macroscopically. Sections of the disc and end plates were prepared and examined microscopically by a pathologist without knowledge of the intradiscal procedure performed.

The average wet weight of disc tissue excised with the Automated Nucleotome probe was 0.7gm per disc. The discs which had undergone trephining alone and those treated with the Automated Nucleotome probe had a similar average reduction of disc space height (15% and 14% respectively). The macroscopic changes were almost identical for both groups and there were similarities on microscopic examination with varying degrees of nuclear cleft formation and infolding of the inner annulus. Macroscopically these discs did not differ from control levels, whereas those discs treated with chymopapain showed marked changes with a reduction of both nuclear and annular volumes together with an average reduction of disc space height of 46%.

The results of this study suggests that any therapeutic effect of percutaneous discectomy with the Automated Nucleotome is likely to be due to the perforation of the annulus alone with the removal of small amounts of nuclear material contributing little, or nothing, to the claimed benefits of the procedure.

THE EFFECTS OF FACETECTOMY ON MOTION SEGMENT BIOMECHANICS, M.J. Schendel, K.B. Wood, J.L. Lewis, J.W. Ogilvie. Department of Orthopaedic Surgery, University of Minnesota, Mpls., MN 55455.

Introduction: Facetectomies are performed in conjunction with decompressive procedures of the lumbar spine. To date, no data is available on the biomechanical effects of partial or complete facetectomies. Current literature illustrates that the facet joint and posterior elements are important aspects of the lumbar spine in both load bearing and motion. In-vitro, human facet joint forces have been measured experimentally by Lorenz (1978), Adams (1980), and Dunlop (1984). Kahmann et. al. (1988) used strain gages on the facet bony process of the canine lumbar spine to measure facet load. The advantage of this method was that the joint and capsule could remain intact while loads were being measured.

Facetectomies are done to relieve impinged nerve roots. The amount of facet removed depends on the pathology, but as more facet is removed there is concern that excess motion can occur or disc and ipsilateral facet will be overloaded. Whether this in fact occurs has not been quantified. The purpose of this study is to measure segment motion and forces on the ipsilateral facet, using the method of Kahmann et. al., before and after partial and complete facetectomy of the human lumbar spine.

Methods: Four fresh human cadaver specimens of the L1/L2 motion segment were tested. Each specimen was debrided of unnecessary soft tissue. Strain gages were mounted on the (L1) inferior articular process of the right facet. The free ends of the vertebrae were potted in a methylmethacrylate mold. An instrumented spatial linkage (ISL), which measures the three-dimensional motion, was attached to the methacrylate end blocks. Bony landmark points at the transverse processes and tip of the spinous process of each vertebra were digitized and used to define local coordinate systems for L1 and L2. Points on the crossbars of each end of the ISL were also digitized to define local coordinate systems for the ISL ends.

Once instrumented, each specimen was mounted in the testing device. Pneumatic actuators were used to apply different loads to the specimens. Extension, flexion, left and right lateral bending, and left and right axial torsion were applied. At each of these load states, data from the strain gages and the ISL were collected. After the normal specimen had been tested, a contralateral hemi-facetectomy was performed on the specimen. The same set of load states were reapplied. A complete contralateral facetectomy was then performed on the specimen, and the loading and data collection repeated. After testing was complete, the facet strain gages and ISL were calibrated. The load in the ipsilateral facet, and the motion of the motion segment were computed from the stored data.

Results: At small extension moments the contact site did not vary between the normal, hemi-facetectomy, and complete facetectomy tests. As the extension moment increased beyond 6 Nm, the contact location moved antero-medially in the facetectomy specimens, and inferiorly in the normal and hemi-facetectomy specimens. The resultant facet load due to extension moments was found to increase after the complete facetectomy, by an average of 71 percent. In right lateral bending, the contact site was constant for all loads for the normal and hemi-facetectomy specimens. For the complete facetectomy specimen, the contact site moved medially with increasing load. Facet loads produced by right lateral bending moments remained the same in all three specimen groups. Left lateral bending moments generated an average increased load of 53 percent between the normal and complete facetectomy groups. The facet load and contact site did not vary significantly for axial torsion loading between each specimen status. No significant motion changes were observed when their respective loads were being applied. Some small secondary rotations were observed after the complete facetectomy was performed. Under applied extension moments, axial, and lateral bend rotations were found to increase on an average of 2.1 degrees.

Discussion/Conclusions: Three aspects of the biomechanics of a motion segment were observed for each motion segment status. The changes in facet load resultant site in the facet joint indicates that, as the extension moment is increased, the specimen rotates axially. This may be due to the missing contralateral facet joint. The loads on the ipsilateral facet joint (after a complete facetectomy) increased with extension and left lateral bending moments. This was expected since the one joint must now resist the same load that two joints had seen previously. While the sample size was small, no significant contact site, load, or motion differences were observed between the normal and hemi-facetectomy group. There was a noticeable change between the normal and facetectomy group.

ANALYSIS OF IN-VIVO CANINE LUMBAR SPINE FACET LOADS. G.R. Buttermann, M.J. Schendel, J.L. Lewis, D.S. Bradford. Biomechanics Laboratory, Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN 55455.

INTRODUCTION: Abnormal loading of cartilage has been related to osteoarthritis of articular joints, including the facet joints of the spine. Facet joint degeneration is considered an important cause of disabling low back pain. Previous studies have shown that degenerative changes of the facet joints in the canine lumbar spine can be induced by alteration of the corresponding intervertebral disc from either chymopapain injection or from discectomy. This animal model of OA is unique since the affected facet joint remains intact and uninvaded. The authors developed a method which is non-

invasive to the facet joint which allows measurement of facet loads and resultant contact locations for various load states, and has been previously applied to in-vitro canine spines. The aim of the current study is to measure facet joint loads in the living animal during various functional activities and obtain baseline data for animals with normal intervertebral discs prior to future studies of facet load changes with disc alteration.

METHODS: The technique entails measuring the strain of the cortical bone on the lateral aspect of the cranial articular process at three or more locations simultaneously in response to loading of the facet joint. Strain measurements obtained during testing are compared to strains obtained at subsequent calibration loading of the caudal facet; this determines resultant facet load contact locations and magnitudes. Four mature, male mongrel dogs (28-31 kg) had five encapsulated strain-gages implanted on the right L3 cranial articular process via a paraspinal muscle-splitting approach. Reliable strain-gage to bone bonding with cyanoacrylate cement required preparing the surface of the articular process by degreasing, wet-sanding and drying, as well as supplying rigid strain relief of lead wires, and tenting of muscles from direct contact with the strain-gages. X-rays of the lumbar spine were obtained pre-operatively to rule out pre-existing facet or disc pathology, and post-operatively to verify the level of the instrumented facet joint. All animals walked normally by post-op day 1. On post-op day 3, simultaneous strain recordings were made at each gage for various static and dynamic activities. Multiple tests of standing and walking were performed to determine in-vivo repeatability. Tests for facet unloading included right torsion and spinal traction under anesthesia with paralyzation. After completion of testing, the lumbar spine was excised, and in-vitro tests of the L2-3 motion segment performed on a previously described loading apparatus. Calibration of specimens involved disarticulation at the L2-3 level, and dividing the articular surface of the instrumented caudal facet into 30 to 40 sectors. A ramp load was applied to the center point of each sector and strain at each gage was recorded simultaneously. For every possible pair of strain-gages, the ratio of the measured strains at each loading point was calculated yielding strain ratio contours for every pair of gages. Comparing in-vivo test strain ratios to the calibration strain ratio contours identified the resultant facet contact load location point. The magnitude of the strain for each gage at the load location point yielded the load predicted by that gage. The facet load was the average of the calculated loads for the five gages.

RESULTS: In general, there were significantly greater facet loads during peak phases of all dynamic tests relative to static tests. The facet was found to be unloaded when the animals were anesthetized/paralyzed and under spinal traction or right torsion. All strain changes, and thus loads, were determined relative to these unloaded states. For the group of four dogs, static tests of sitting, sitting erect, lying prone, lying in a left lateral decubitus position, and flexion revealed facet loads ranging from 0 - 60N. Average standing (20 trials) loads for each dog were 36+/-10N; 24+/-15N, 26+/-14N, and 28+/-20N. Group results of dynamic tests for right and left turning, sit to stand, climbing stairs, standing/walking erect revealed loads ranging from 55 - 180N. Average peak dynamic loads in walking (7 trials) for each dog were 109+/-32N; 95+/-29N; 115+/-28N; and 96+/-11N. These peak values corresponded with the stance phase of the ipsilateral lower extremity. Relative resultant contact load locations on the facet tended to be in the central/caudal portion of the facet in extension activities, central/cranial in standing, and cranial/ventral in flexion or right turning activities. Right turning contact locations were ventral/cranial to left turning locations. Resultant load locations at peak loading during walking were in the central region of the facet, whereas resultant load locations at minimum loading during walking were relatively craniad.

DISCUSSION: A recently developed technique for non-invasive measurement of facet loading was applied to an in-vivo canine model. Resultant facet load magnitudes and their contact locations were determined for static and dynamic activities. Facet loading during active use of the back muscles was greater than when the animal was in a passive static posture. The facet load magnitudes were in the range of loads determined from previous in-vitro tests for a variety of applied load states. Assuming that the loads are distributed over at least one-third of the joint surface, our results suggest that the facet cartilage may experience contact pressures up to 2MPa during peak loading. Estimates for thicker human articular cartilage range from 1 to 10^{+}MPa. The importance of quantifying loads in the facet joint is not only for an improved understanding of spine biomechanics, but also for quantifying load changes with degeneration of the facet joint and/or of the disc. The interrelation of facet degeneration to disc alteration which has been found in dogs, may occur in humans yet the issue remains controversial. Some in-vitro studies have found an increase in facet load and a change in loading sites with disc alteration, whereas others found only a change in loading sites. In order to address this issue, quantification of in-vivo facet joint loads is essential. The current technique has been found to be adequate for short term in-vivo studies to establish baseline data for a group of animals with unaltered discs. Currently, the technique is being modified in order to attempt to monitor facet load changes with alteration of the disc over extended periods.

CONDUCTION VELOCITIES OF PYRAMIDAL TRACT FIBRES AND LUMBAR MOTOR NERVE ROOTS: NORMAL VALUES

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Introduction: To date, pyramidal tract and motor root conduction velocities in man have been determined by indirect surface measurements or by intraoperative epidural recordings only. Data based on precise anatomical and neurophysiological measurements in awake subjects is not obtainable, neither in the neurophysiological nor in the anatomical literature. We performed measurements of spinal cord and individual lumbar nerve root lengths in 20 dissected cadavers and correlated these data with the results of pyramidal tract and motor root conduction time studies by means of motor evoked potentials in 46 healthy subjects.

The aim of our study was to obtain normal values of the length of different segments of the central and proximal peripheral motor pathways. These segments were chosen according to the sites of stimulation when performing motor evoked potentials using the magnetic stimulator. Conduction velocities could thus be calculated for the different segments of the motor pathways.

Materials and Methods: 20 whole body cadavers of 144 to 191 cm size were dissected. The following distances were measured: motor cortex - exit of L1, L2, L3, L4, L5, S1, S2, S3 motor root from the spinal cord, i.e. level of the corresponding anterior horn cells, exit of the motor roots from the spinal cord - exit of the nerve roots from the intervertebral foramen. Magnetic stimulation of the motor cortex and motor root as well as conventional neurography was performed in 46 healthy adults of 150 to 191 cm size. Recordings were performed from the quadriceps femoris (L4), tibialis anterior (L5), extensor digitorum brevis (L5), and external anal sphincter muscles (S3).

Results: The distances between motor cortex and the level of the anterior horn cell were L1:50.2 cm, L2: 51.3 cm, L3: 52.3 cm, L4: 53.7 cm, L5: 54.4 cm, S1: 55.2 cm, S2: 56.7 cm and S3 56.3 cm (the length of the S3 root could only be determined in two cases). The length of the nerve roots were: L1: 10.3 cm, L2: 12.5 cm, L3: 14.8 cm, L4: 16.2 cm, L5: 17.5 cm, S1: 18.0 cm, S2: 18.9 cm, S3: 19 cm. The conduction velocity calculated for the distance motor cortex - anterior horn cells of the L5 segment was 48.1 m/sec. The conduction velocity of the motor root between its exit from the spinal cord and its exit from the intervertebral foramen was 78.4 m/sec. The overall conduction velocities between motor cortex and exit of the nerve roots from the intervertebral foramen were L4: 53.8 and L5: 54.0, i.e. 53.6 m/sec. It was 36.5 m/sec to the S3 root. The spinal cord motor conduction velocity between the C7 and L5 segments (31.8 cm) was 57.8 m/sec.

Discussion: These results are in accord with reports on intraoperative epidural measurements and calculations from surface measurements as well as recordings in monkeys. Critical interpretation, however, has to take account of the fact that anatomical measurements were performed on cadavers whereas neurophysiological recordings were obtained from healthy subjects. Nevertheless our results emphasize the validity of magnetic stimulation for the evaluation of pyramidal tract and motor root conduction times.

IMPORTANCE OF ONSET RATE FOR THE DEGREE OF INJURY IN NERVE COMPRESSION SYNDROMES. An experimental study on the porcine cauda equina

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Nerve tissue might be subjected to compression at various onset rates. For instance the onset rate of a trauma is far more rapid than that of a degenerative disorders or tumors. The importance of the onset rate of a mechanical deformation for the degree of nerve injury has only just recently been noted, but the basic mechanisms are not fully understood. *In the present study, the differences* in effects between a rapid and a slow onset of experimental compression were studied regarding nutritional supply and function of the pig cauda equina.

Material & Methods: A total of 74 pigs, weighing 25-40 kg, were anaesthetized with ketamine, methomidate chloride and azaperonum, and ventilated on a respirator. The cauda equina was exposed by removing laminae and facet-joints of the 1st and 2nd coccygeal vertebrae. An inflatable balloon was placed across the spinal canal, over