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In vitro measurement of pressure in intervertebral discs and annulus fibrosus with and without annular tears during discography

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Abstract

BACKGROUND CONTEXT: Discogram studies have shown that pain reproduction correlates with the extent of annular disruption. However, it has not been assessed if pressure changes in the annulus fibrosus vary incrementally with intradiscal pressure.

PURPOSE: To determine the relationship between intradiscal pressure and outer annular pressure during discography in intervertebral discs with and without annular tears.

STUDY DESIGN: Intradiscal and periannular pressures were measured simultaneously in vitro during intradiscal injection in porcine cadaver spines.

METHODS: Twenty fresh porcine cadaver lumbar spines with intervening discs were tested. Intradiscal and periannular pressures were measured simultaneously using two pressure sensors during intradiscal contrast injection. The tip of a 25-gauge needle connected with a pressure manometer was placed in the center of the nucleus pulposus. A second pressure transducer was located at the outer third of the annulus fibrosus. Needle and transducer locations were confirmed by fluoroscopy. To compare the intact and torn annulus fibrosus, annular disruptions were created with a 20-gauge needle and confirmed by fluoroscopy.

RESULTS: During intradiscal injections of discs with an intact annulus, annulus fibrosus pressure remained low and a sharp increase in intradiscal pressure was observed. Significantly higher pressures were noted in the outer annulus in discs with annular tears ($p < .01$). Mean pressures at the central nucleus pulposus, the outer third of intact annuli and torn annuli were 93.4 ± 40.9 psi, 14.8 ± 1.9 psi and 85.7 ± 24.8 psi, respectively.

CONCLUSIONS: Volumetric injection of intervertebral discs with a torn annulus fibrosis during discography may increase intra-annular pressure similar to the increase in pressure that may occur during spinal loading activities. This effect may not occur in discs with an intact annulus fibrosus. © 2004 Elsevier Inc. All rights reserved.

Keywords:

Discography; Intradiscal pressure; Periannular pressure; Annular tear

Introduction

The intervertebral disc is a common source of chronic axial back pain and is the primary pain source in the anterior spinal column [1–3]. Lumbar discography is the physiologic test to diagnose patients with chronic persistent low back

pain and referred buttock and leg pain, historically termed internal disc disruption syndrome [4–9]. However, painful, internal disc disruption may have no external features. The contour of the disc remains essentially normal, and consequently the disc may afford negative computed tomography, myelography and low field Tesla magnetic resonance imaging [10]. Intradiscal injection, such as discography, is conceptually an extension of clinical examination, tantamount to palpating for tenderness [11]. Using an injection of contrast dye, discography identifies a painful intervertebral disc by distension or direct stimulation of the disc pain source (eg, torn annulus, granulation tissues and hypertrophic low-threshold nociceptors).

FDA device/drug status: not applicable.

Nothing of value received from a commercial entity related to this research.

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The probability of discogenic pain increases the further a radial fissure extends into the outer annulus [11]. Pain reproduction during discography correlates with the extent of annular disruption [12]. Although discography is widely used, the exact pressure applied on an outer annular pain focus during intradiscal injection remains unknown, and the effect of annular tears on annulus fibrosus pressure and intradiscal pressure during discography has not been examined.

The purpose of this study is 1) to evaluate periannular pressure changes correlated with the tensional stress caused by fluid injection during intradiscal injection, and 2) to assess the relationship between intradiscal pressure and outer annular pressure with and without annular tears during discography.

Materials and methods

Approach

This study consisted of two portions. In the first portion we evaluated differences in pressure patterns among different tissues, including the nucleus pulposus and the outer third of the annulus fibrosus during intradiscal injection. The second portion evaluated differences in pressure responses using a torn annulus fibrosus as a model of discogenic pain during intradiscal injections, such as discography.

Preparation of spine specimens

Twenty fresh porcine thoracolumbar vertebrae with intervening discs were obtained. All muscular structures were removed. Lower thoracic and lumbar intervertebral discs were separated by means of dissection at the middle of the vertebral body. Each specimen was frozen at -20°C in double plastic bags and kept moist during storage. Before testing, each specimen was thawed to room temperature in double plastic bags for 4 to 6 hours and then soaked in normal saline at 37°C in a plastic bag for 24 hours. To compare intra-annular pressure changes between the intact and torn annulus fibrosus, annular disruptions were created by movements of a 20-gauge needle and were confirmed by fluoroscopic contrast dye injections. Needle movements were discontinued if contrast revealed a small fissure at the junction of the middle and outer annuli. The tip of the Xducer (MMI Medical Measurements, Hackensack, NJ) was placed inside of the outer third of the annulus. During discography, the intra-annular pressure is increased by distension of the nucleus pulposus. Horizontal positioning of the pressure sensor, with the instrument oriented toward the disc center, affords more reliable detection of annular pressure changes than the vertical orientation due to distension of contrast dye. We tried to keep the Xducer sensor faced toward the disc center without directly contacting contrast dye (Fig. 1).

Discography

Discography was performed using a 25-gauge needle. The needle tip was placed into the center of the nucleus

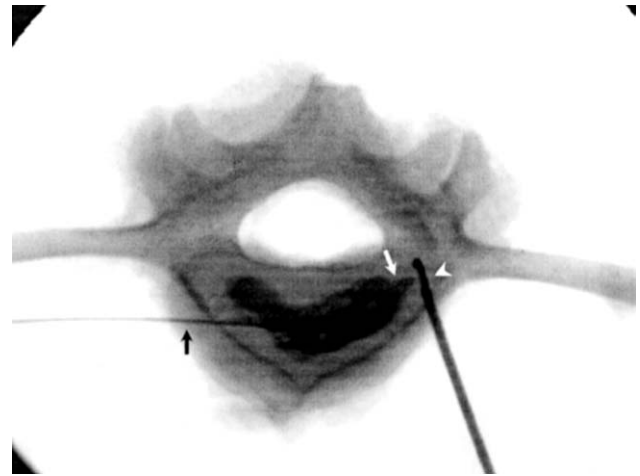


Fig. 1. Intradiscal and periannular pressures were measured simultaneously using two pressure sensors during intradiscal contrast injection. The tip of a 25-gauge needle connected to a pressure manometer was placed in the center of the nucleus pulposus (black arrow). A second pressure transducer was located at the outer third of the annulus fibrosus (white arrow). Annular disruptions were created with a 20-gauge needle and confirmed by fluoroscopy (arrow head).

pulposus laterally. Precise positioning of the needle tip was confirmed by fluoroscopy. Omnipaque (Winthrop-Breon Laboratory, New York, NY), a water-soluble contrast agent, was used for every injection to confirm the presence of an annular tear.

Pressure measurement

We used two pressure sensors simultaneously during injections. One sensor (Merit System; Merit Medical Systems, Inc., South Jordan, UT) was attached to an injection pump and a 25-gauge needle was inserted into the nucleus pulposus. A second sensor (Xducer) with a separate sensor tip was also used. The Xducer sensor and the Merit System sensor were first calibrated with a manual pressure gauge. Readings from the pressure gauge were used to adjust the baseline and gain of the Xducer pressure sensor before insertion into the nucleus pulposus. We then proceeded with insertion. Intradiscal pressures on the Merit System sensor were equal to pressure readings on the Xducer ($r=0.99$, $p<.01$; see Fig. 2). Pressure measurements were performed during volumetric injection. The static pressure (relative to the opening pressure) was also continuously monitored and recorded. To measure pressure differences in the disc, pressure sensors were introduced into the nucleus pulposus and the outer third of the annulus. After confirming the validity of the two measuring systems, the 25-gauge needle tip of the Merit System was introduced into the central nucleus pulposus and the tip of the Xducer was positioned in the outer annulus fibrosus of an intact disc. During the intradiscal injection with the infusion pump attached to Merit System, pressure differences between the central nucleus pulposus and the outer annulus fibrosus were determined.

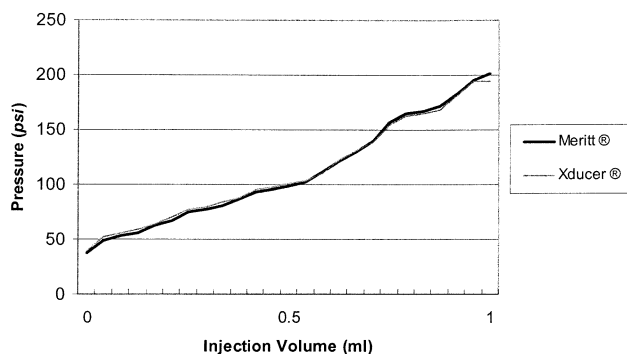


Fig. 2. Comparison of Merritt System and Xducer dynamic pressures in an L4-L5 disc during dye injection (1 ml total volume).

To compare pressure differences between an intact and torn annulus fibrosus, annular disruptions were created with a 20-gauge needle and confirmed by fluoroscopic contrast dye injections. Similar pressure measurements using the Merit System and the Xducer were repeated within torn annular discs. Pressure differences within the nucleus pulposus were obtained from the opening pressures. Intra-annular pressures were based on the starting pressure.

Results

Pressures in the central nucleus pulposus and the outer annulus fibrosus with intact discs

During injection, the intradiscal pressure was consistently above 150 psi, but the outer annular pressure remained at a relatively lower pressure (Fig. 3, Table 1).

Pressure in the central nucleus pulposus and outer annulus fibrosus with torn discs

The outer annular pressure consistently increased during incremental intradiscal injection of 1 ml contrast media (Fig. 4, Table 1). During intradiscal injection, the periannular

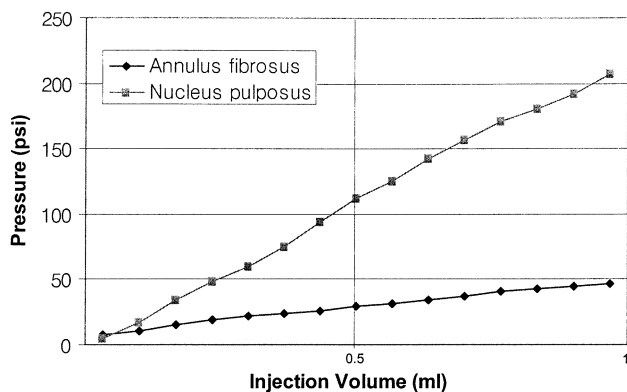


Fig. 3. Pressure changes in the annulus fibrosus and nucleus pulposus without annular tears during injection of 1 ml dye into the annulus fibrosus and the nucleus pulposus.

Table 1

Intradiscal pressure during injection of 1 ml contrast dye in discs with and without an annular tear

	Nucleus pulposus pressure (psi)		Annulus fibrosus pressure (psi)	
	Initial	Peak	Initial	Peak
(-) Annulus tear	11.2±8.4	199.9±11.8	9.2±6.7	45.8±11.3
(+) Annulus tear	11.0±8.7	158.0±19.2	9.8±8.1	115.2±17.3

Data are mean±standard deviation.

pressure in the intact annulus fibrosus remained low, in comparison to a marked elevation of pressure observed in the central nucleus pulposus. With a torn annulus, the periannular pressure continuously increased proportionally to the intradiscal pressure.

Pressure differences between the central nucleus pulposus and outer annulus fibrosus with and without annular tears

In intact discs, pressure differences between the nucleus pulposus and the annulus fibrosus increased with contrast dye volume. However, in torn discs the differences were approximately zero until 45 psi, when a pressure difference was observed (Fig. 5).

In intact discs, the ratio of pressures between the nucleus pulposus and the annulus fibrosus decreased with volume until the pressure in the nucleus pulposus was 94 psi. Thereafter, the pressure ratio reached a plateau of approximately 0.25 psi. In torn discs the ratios decreased until the pressure in the nucleus pulposus was 60 psi, and then the ratio reached a plateau at approximately 0.8 psi, in contrast to the marked elevation of pressure observed in the central nucleus pulposus (Fig. 6).

Discussion

Discography is conceptually an extension of clinical examination [11]. A precision injection of contrast dye into the disc nucleus stimulates nerve endings [13], permitting

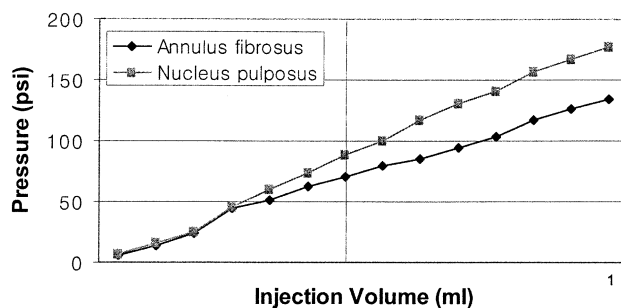


Fig. 4. Comparison of pressure changes in discs with annular tears during injection of dye (total volume 1 ml) into the annulus fibrosus and nucleus pulposus.

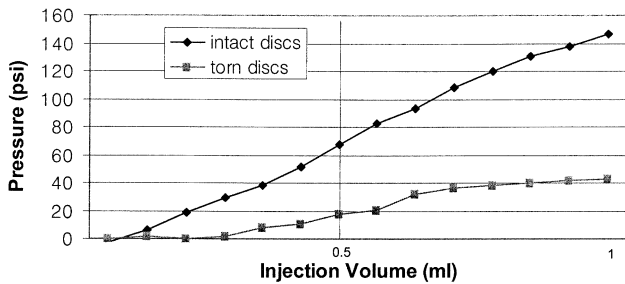


Fig. 5. Difference in pressure between the nucleus pulposus and annulus fibrosus during injection of dye in torn and intact discs (total volume 1 ml).

diagnosis of discogenic pain by pain provocation. Discogenic pain is believed to arise from annular fissures extending from the nucleus to the outer annulus. The outer third of the annulus fibrosus is regularly innervated, but the middle third may not be innervated. As a result, the probability of discogenic pain increases the further a radial fissure extends into the annulus [11]. The intensity and persistence of pain suggests peripheral sensitization and varying degrees of central enhancement.

Although the outer annulus is the main source of discogenic pain, most experiments have focused on central nuclear pressure changes during a range of loading. To our knowledge, this is the first peer-reviewed paper examining the relationship between annular and central nuclear pressure during discography.

During intradiscal injection, the periannular pressure in the intact annulus fibrosus remained at a low pressure, compared with a marked elevation of pressure in the central nucleus pulposus. With a torn annulus, the periannular pressure increased proportionally to the elevation of intradiscal pressure. These data suggest that the multilayered, lamellated and strong annulus fibrosus may hold the pressure until breakdown. Within a torn annulus, the lamellated structure cannot maintain pressure, causing pressure elevation during intradiscal injection.

These results have shown that a discogram cannot induce sufficient annular stimulation to provoke pain with an intact

inner annulus, possibly producing a false negative. Discography induces pressures that differ from the pressure distribution of normal activities, producing stimulation by means of an expanding force, with peak force on nucleus pulposus. Normal activities involve compression forces with peak pressures occurring in the outer annulus. During normal activities over a range of loading conditions, the largest stresses in normal discs appear to occur in the annulus, not the nucleus [14].

It was not surprising that all studies, such as those of Walsh, Carragee, and Derby, showed negative responses (no false positives) with intact inner annulus discs [15–17]. If there is a symptomatic disc with a torn outer annulus and an intact inner annulus, injection into the nucleus may not achieve pressures similar to those required to evoke pain. Transfer of contrast and pressure to the outer annulus would not be permitted because of the intact inner annulus. This scenario could in principle afford false negatives in a small number of patients with discogenic pain.

Our results have shown that the pressure increment of outer annulus in an intact disc was only 20 to 25 psi if intradiscal pressure was increased to 100 psi, a very high pressure stimulation in clinical discography. Considering that the porcine disc is smaller than the human disc, this pressure level is insufficient to detect or diagnose mechanical or pathologic pressure-sensitive discs, which are painful at pressures of 15 to 50 psi. However, the torn annulus showed approximately 80 psi at the outer annulus with 100 psi intradiscal stimulation. This increment could be enough to stimulate nonpathologic pressure-sensitive discs, which provoke pain at greater than 50 psi stimulation.

Extrapolation of results from *in vitro* animal models to humans is one shortcoming of the present work. However, identical experiments using *in vivo* human discs are rarely possible, because in this experiment two or more pressure sensors were introduced. In addition, the discs of the porcine spine are smaller than those of humans. This study is a first step toward further research using human cadaver spines as well as *in vivo* human intradiscal studies examining perinuclear pressure changes during intradiscal injection.

Intra-nuclear injection of contrast into intervertebral discs with torn annulus fibrosus will increase pressures in the outer annulus proportional to the increase in the intra-nuclear pressure. In addition, the absolute values of pressure will be close to the measured intra-nuclear pressure. It is therefore probable that the measured intra-nuclear pressure during manometric discography accurately reflects the increase in outer annular pressure and as such will permit the evaluation of pain caused by a graded increase in outer annular tension created by increasing volumes of contrast medium. During intradiscal injection, the periannular pressure in the intact annulus fibrosus remained at a low pressure. Discs with an intact annulus may need to be evaluated using a different technique [18,19].

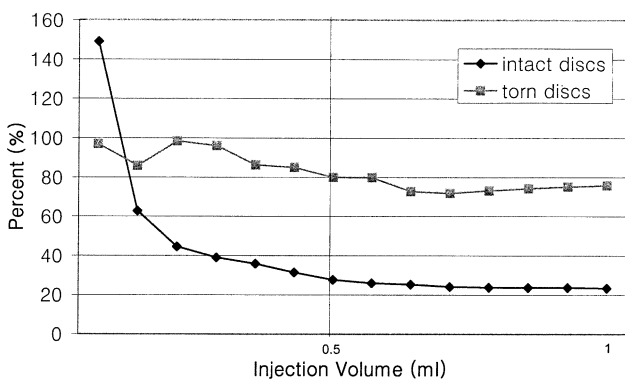


Fig. 6. The ratio of nucleus pulposus and annulus fibrosus pressures during injection of 1 ml dye in intact and torn discs.

Acknowledgments

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