SPINE Volume 28, Number 2, pp 107–113

Ultrasound Imaging of the Intervertebral Disc

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Study Design. *In vitro* ultrasound imaging of dog intervertebral discs was performed.

Objective. To determine the reliability of ultrasound imaging in the detection of structural changes associated with disc pathology.

Summary of Background Data. Little work has been done to evaluate the potential applications of ultrasound in the imaging of intervertebral discs. Initial *in vitro* studies, however, have indicated that ultrasound imaging is capable of producing images of the disc that contain a high degree of structural information.

Methods. Explanted lumbosacral discs from 13 nonchondrodystrophic dogs, mean age 5 years and 8 months, were stripped of all surrounding tissues and scanned using ultrasound before being sectioned and photographed. The ultrasound images were graded according to criteria chosen to reflect progressive stages of disc degeneration, allowing correlation with the grading scale used to assess the photographic images of the discs. Grades assigned to each disc were compared using Cronbach's alpha to determine the reliability of the images obtained using ultrasound.

Results. The results for the anterior anulus fibrosus produced an alpha value of 0.924; those for the nucleus pulposus produced a value of 0.821; whereas those for the posterior anulus fibrosus produced a value of 0.882. Where the grade given to the ultrasound image did not match those given in visual assessment, the disparity was never greater than one grade. Ultrasound images of several discs demonstrated echo patterns that matched, in both location and appearance, real structural defects identifiable on the sectioned discs.

Conclusions. Ultrasound images of intervertebral discs relate well to their pathologic condition. In addition, ultrasound is able to locate specific pathologic defects. [Key words: dog, intervertebral disc, pathology, ultrasound] **Spine 2003;28:107–113**

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Supported by United Bristol Healthcare Trust, University of Bristol, and Petsavers.
Acknowledgment date: July 31, 2001. Second revision date: May 3, 2002.
Acceptance date: May 6, 2002.
Device status/drug statement: The manuscript submitted does not contain information about medical device(s)/drug(s).
Conflict of interest: Institutional funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.
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It has been clear for some time that the intervertebral discs are capable of producing pain. Mechanical provocation of the intervertebral disc and provocation discography both have been shown to elicit back pain.[6,8]

Currently, the pathology of disc pain remains unclear. Alterations in the structure of the intervertebral discs are thought to be a major source of pain, especially those involving the innervated outer one third of the anulus. Indeed, the correlation between the reproduction of a patient's back pain and the presence of a radial fissure reaching the outer one third of the anulus is stronger than that for any other demonstrable morphologic abnormality.[12] Circumferential clefts and rim tears of the outer anulus are additional structural defects commonly observed in the innervated, and therefore potentially painful, outer one third of the anulus.[15]

Advances in medical imaging have been applied both *in vivo* and *in vitro* in an effort to provide a better understanding of the types of disc dysfunction that lead to disc pain and of their progression. Currently, the most favored techniques for imaging the intervertebral discs are diskography and magnetic resonance imaging (MRI). Neither method, however, is entirely suited to this particular task. Diskography involves the injection of a radio-opaque contrast medium into the nucleus, followed by either plain radiography or computed tomography to image the distribution of contrast. This technique can detect only the presence of fissures that extend from the nucleus into the anulus, and not peripheral fissures that also are thought to result in disc degeneration or pain.[10,14] The procedure is invasive, gives a relatively high dose of ionizing radiation, and carries a risk of infection.[3,5]

Magnetic resonance imaging provides a high level of contrast between the disc and other structures in the spine, and undoubtedly has improved ability to identify degenerative discs. Despite this, the significance of MR images for identifying symptomatic discs and their relevance to disc structure remains controversial.[13,16] Abnormal MR images have been shown to occur in asymptomatic discs.[2,4] In addition, MRI has been shown to fail in the identification of certain clinically significant structural lesions.[20] If any progress is to be made in understanding disc pathology and the resulting discogenic back pain, an imaging technique capable of demonstrating significant structural lesions and their progression within the disc is essential.

Ultrasound imaging is a flexible, noninvasive technique that can be used to provide high-resolution images of soft tissues. So far, little work has been done to evaluate the potential applications of ultrasound in the imaging of intervertebral discs. If capable of producing images of the intervertebral disc containing an equivalent or increased amount of useful information as compared with MRI, ultrasound would be an attractive alternative imaging method. An ultrasound scanner is much cheaper than an MRI scanner in terms of both initial outlay and running costs. No contraindications to ultrasound scanning exist, unlike MRI, in which the presence of pacemakers, aneurysm clips and certain implants may prevent scanning from taking place. Patients or tissue specimens must be moved to the site of the MRI scanner, and the time required to perform MRI scans can be significant. Ultrasound scanners are extremely mobile; scanning time is very quick; and tissue structures may be observed in real time. Initial *in vivo* studies have indicated that ultrasound imaging is capable of producing images of the disc that contain high degree of structural information.[9] How accurately ultrasound is able to depict changes in disc structure is currently unknown.

The objectives of this study were to determine the reliability of a scale for grading ultrasound images of the disc with regard to degeneration, and to investigate the ability of ultrasound to detect specific focal lesions. This was accomplished using a nonchondrodystrophoid dog model, chosen because of strong similarities, in terms of gross structure and degenerative changes, with human discs.[7]

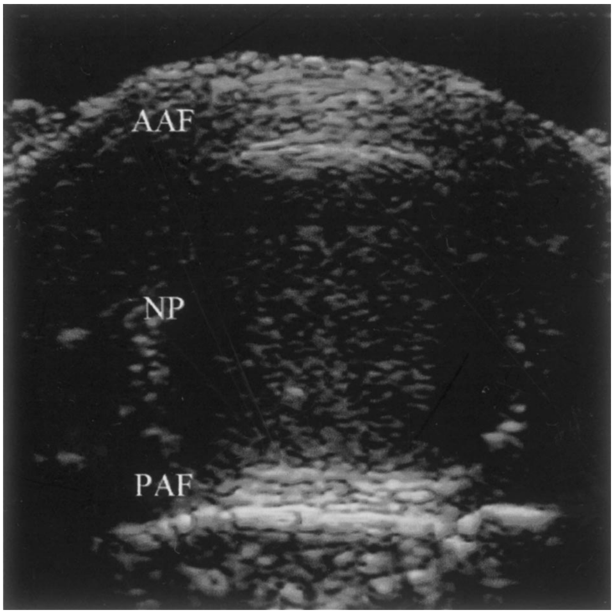

Figure 1. Ultrasound image of a normal dog intervertebral disc taken in a transverse direction. AAF, anterior anulus fibrosus; NP, nucleus pulposus; PAF, posterior anulus fibrosus.

■ Materials and Methods

This study used 13 nonchondrodystrophoid dogs of different breeds with an age range of 6 months to 14 years (average age, 5 years and 8 months). After euthanasia, the lumbosacral disc and adjacent vertebrae were removed from each dog. Each specimen then was screened radiographically for evidence of osseous anomaly or disc space narrowing. All surrounding tissue was dissected away from the specimen, leaving only the lumbosacral disc and adjoining vertebrae. The specimens were wrapped in plastic film to prevent dehydration and placed in frozen storage at −20 C.

Before imaging, each segment was defrosted at 4 C for 12 hours. Ultrasonic imaging of the lumbosacral discs was performed in a water bath at room temperature using a 7.5-MHz linear array transducer in conjunction with the Acoustic Imaging 5200 imaging system (Acoustic Imaging Technologies, Phoenix, AZ). The vertebral segments were placed on their side with a metal block 6 cm high placed beneath each vertebra. These blocks raised the specimen off the bottom of the water bath, preventing interference of the strong echoes from the smooth base of the bath with the echoes received from the tissue of the disc.

The ultrasound transducer was clamped in place with the scanning face below the surface of the water, orientated centrally above the disc in a transverse direction 0.5 cm from the tissue surface. This positioning enabled use of the maximum number of focal zones available to achieve the highest image quality possible across the entire width of the disc.

A single ultrasound image was taken in a transverse plane through the center of each disc. Figure 1 shows the ultrasonic appearance of a normal healthy nonchondrodystrophic dog disc scanned using this technique. The internal structure of the disc is clearly visible. The anulus fibrosus appears hyperechoic, with a pattern of parallel, linear echoes showing the lamella structure in these regions. The soft gel-like nucleus appears hypoechoic. A single machine operator performed all the ultrasound imaging, and all the machine settings remained constant.

After the completion of ultrasound imaging, each disc was transected using a single cut in the transverse plane. The cut surface of the disc then was photographed, and the photographs were assessed using a scale with four grades (Table1). This grading system is an established method used to rate the degree of pathologic change in a disc on the basis of visible changes in disc structure.[1]

A separate scale was designed to allow assessment of the ultrasound images obtained from the discs. A scale of four grades was created to reflect the expected ultrasonic appearance of the disc at each of the stages of degeneration described in the photographic grading (Table 1). This scale was designed by first determining the characteristic ultrasound appearance of a normal healthy disc: structural coherence of lamella echoes in the anulus as well as uniformity and lack of echogenic foci in the nucleus (Figure 1). Predictions as to how this normal ultrasonic appearance would change as degeneration progressed in both the anulus and nucleus then were made to determine the criteria for Grades 2, 3, and 4.

For the purpose of assessment, images of the discs were split into three regions: the anterior anulus fibrosus, the nucleus pulposus, and the posterior anulus fibrosus. Each of these regions was graded independently. The ultrasound images were assessed in a blinded manner by a single observer. This observer was a researcher competent in the use of ultrasound, but with no prior experience in imaging pathologic tissue, disc, or the like. The photographic images were assessed in a blinded manner by two separate observers, both with some prior experience in grading photographic images of discs for pathology. A third independent observer was used on three occasions to confirm the appropriate grade of a photographic image when the two observers were unable to agree. The results obtained under the two different grading systems were then compared using Cron-

Table 1. Scales Used to Grade Discs for Degeneration Based Upon Photographic and Ultrasonic Appearance

Grade	Criteria for Grading of Photographic Images of the Intervertebral Discs	Criteria for Grading of Ultrasonic Images of the Intervertebral Discs
1	The disc is white and usually shows no sign of structural disruption to the annulus or vertebral body endplates. The distinction between the annulus and nucleus is obvious only on thin saggital sections; in these, the nucleus appears to be gelatinous or even translucent.	Lamellae within the annulus are clearly visible and the intensity level across the annulus is constant. The nucleus is clearly distinct from the annulus and has a constant very low echo level, appearing hypoechoic.
2	The disc is cream-colored and usually shows no sign of structural disruption. The nucleus appears to be fibrous and rather yellow, but is still soft. The concentric lamellae of the annulus are distinct and intact.	There is some loss of lamella distinction within the annulus, plus an area(s) of slightly increased echogenicity with diffuse margins. Within the nucleus there is an area(s) of slightly increased echogenicity with diffuse margins, although the overall echo level is still low.
3	There are signs of disruption of the annulus or adjacent endplates. The nucleus is fibrous, dry and often discoloured. The annulus usually contains fissures and splits.	There is total loss of lamella distinction within the annulus. Local clear hyperechoic areas are observed in the nucleus, along with a loss of distinction between annulus and nucleus.
4	Severe disruption makes it difficult to distinguish between annulus and nucleus. The nucleus is often brown and fibrous and the annulus contains gross radial or circumferential fissures.	Local clear hyperechoic areas and acoustic shadows are observed within the annulus/nucleus along with possible loss of ultrasound transmission.

bach's alpha test to determine the reliability of assessing disc degeneration using ultrasound.

After this general grading, both sets of disc images were reassessed for signs of specific circumferential tears, radial fissures, and nuclear fissures. The three regions of the disc were again graded independently, and separate observers assessed the ultrasound and photographic images.

Results

Reliability of the Ultrasound Grading Scale

Table 2 indicates the number of occasions on which Grades 1 to 4 were assigned in each region of the intervertebral disc under each imaging method. The mean absolute difference in these grades is shown in Figure 2.

The ultrasound grade given for the anterior anulus fibrosus matched that assigned under the photographic grading system for 84% of the discs. In the assessment of the nucleus pulposus, 70% of the grades matched, whereas for the posterior anulus fibrosus, grading was in agreement 77% of the time (Table 3).

Cronbach's alpha test returned alpha values of 0.92 for the anterior anulus fibrosus, 0.82 for the nucleus pulposus, and 0.88 for the posterior anulus fibrosus. In cases for which the grade assigned during the assessment of the ultrasound images did not match that given during the photographic grading, the disparity was never greater than one grade.

Detection of Specific Pathologic Defects

Before this study, little was known about the ability of ultrasound to detect pathologic defects in the intervertebral disc. A previous study by Tervonen[17] described the presence of fissures as hyperechoic. However, it is difficult to rely on this given that the same study described the appearance of a normal disc as evenly hypoechoic, a finding that since has been disproved by McNally *et al.*[9]

Given that there are no accurate descriptions of the ultrasonic appearance of pathologic defects, an attempt was made to identify the presence of such lesions using just one simple criterion: an area demonstrating an abnormal pattern or intensity of echoes relative to the appearance of the surrounding section of tissue. Figure 3 shows how this was accomplished. In Figure 3a a line hyperechoic relative to the surrounding area can be seen in the anterior anulus fibrosus. As shown in Figure 3b, a photographic image of the transected disc, the position of this hyperechoic echo corresponds both in shape and position to a circumferential tear in the anulus. In the nucleus pulposus, a central area of increased echo levels relative to the rest of the nucleus pulposus corresponds to an area of cracks on the photographic image. The large cavity-like defect in the posterior anulus fibrosus is apparent on the ultrasound image as a defect of similar shape and position. Figure 4 shows the relation between the ultrasonic and photographic images of a second disc.

Table 4 indicates the ability of ultrasound to detect specific pathologic defects. Ultrasound was able to demonstrate all the defects identified on the photographic images of the transected discs, which occurred within the region interrogated by the ultrasound beam. In four sam-

Table 2. The Number of Times Each Grade was Assigned in Each Region of the Disc

	Number of Each Grade Recorded in Each Region of the Disc											
	Grade 1			Grade 2			Grade 3			Grade 4		
Region of disc	AAF	NP	PAF	AAF	NP	PAF	AAF	NP	PAF	AAF	NP	PAF
Ultrasound images	2	2	1	7	5	5	4	5	6	0	1	1
Photographic images	2	2	1	8	7	6	2	3	5	1	1	1

AAF = anterior annulus fibrosus; NP = nucleus pulposus; PAF = posterior annulus fibrosus.

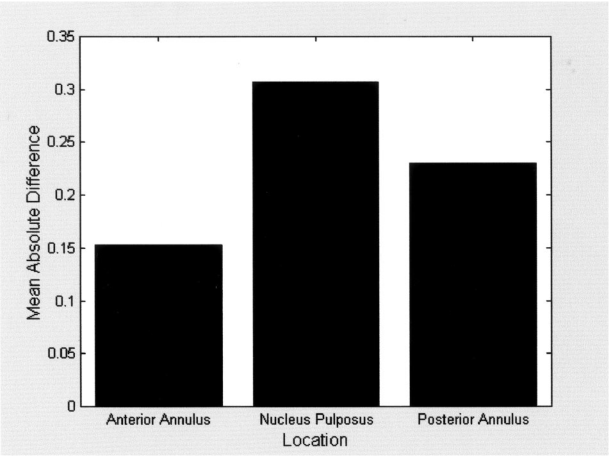

Figure 2. Graph showing the mean absolute difference in grades assigned to each area of the disc for comparison of the photographic and ultrasonic grading scales (n = 13).

Table 3. The Number of Samples in Which the Ultrasound Grade and Visual Grade Were Matched

Region of the Disc	Number of Matched Grades	Number of Unmatched Grades
Anterior annulus fibrosus	11	2
Nucleus pulposus	9	4
Posterior annulus fibrosus	10	3

ples, the ultrasound images appeared to demonstrate defects that were unidentifiable on the photographic images: once in the region of the anterior anulus fibrosus and on three occasions in the region of the nucleus pulposus.

■ Discussion

Ultrasound has been a popular choice for the imaging of soft tissues since the 1960s. Despite its use to study a wide variety of soft tissues, very little has been done to investigate the ability of ultrasound to provide useful clinical images of the intervertebral discs. A study by Tervonen *et al*[18] demonstrated that the acoustic properties of the intervertebral discs made them suitable for imaging using the frequencies available on current clinical scanners. After this, attempts were made to image the lumbar discs *in vivo* using a transabdominal approach that involved placing the transducer on the skin surface of the abdomen and scanning through the underlying tissue. Normal discs were demonstrated to be evenly hypoechoic, whereas fissures appeared hyperechoic.[18] The evenly hypoechoic appearance of a normal disc is somewhat unexpected given the heterogeneous nature of intervertebral disc structure. However, degradation in image quality and resolution, caused by the transabdominal approach adopted in this study, may have been a factor in the inadequate visualization of disc structure.

The reliability of ultrasound in detecting structural change was shown to be variable,[11,19] and after the relatively poor performance of ultrasound in these studies, little work has been undertaken in this area. Recent work, however, indicates that the potential of ultrasound for imaging the intervertebral disc may be far greater than previously thought.[9] Initial *in vitro* imaging also has shown that ultrasound is able to demonstrate internal disc structure (Figure 1).

Reliability of the Ultrasound Grading Scale

Cronbach's alpha is a measure of internal consistency. In this situation, its value indicates the reliability of the current scale for determining the degree of disc degeneration. An alpha above 0.8 is considered very good, showing a high degree of reliability. The results of this study exceeded 0.8 in all three areas of the disc. Through use of the ultrasound image grading scale, it is possible to determine the degenerative state of an intervertebral disc accurately on the basis of its ultrasonic appearance. The high degree of success achieved with this initial study suggests that ultrasound could play an important role in the investigation of intervertebral disc pathology.

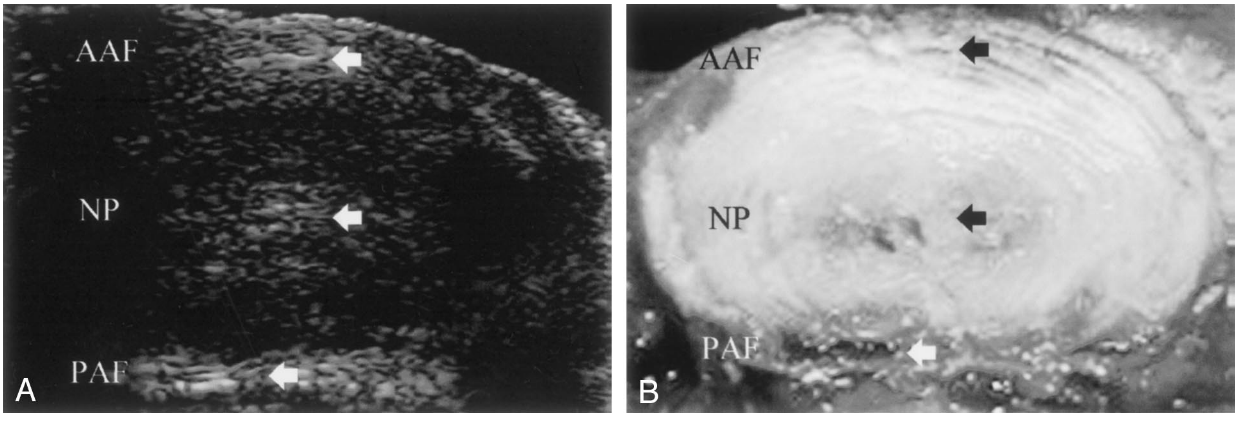

Figure 3. **A,** Ultrasonic image of an intervertebral disc. Arrows indicate the positions of focal structural defects. **B,** Photographic image of the disc pictured in **A.** Arrows indicate the sites of focal defects.

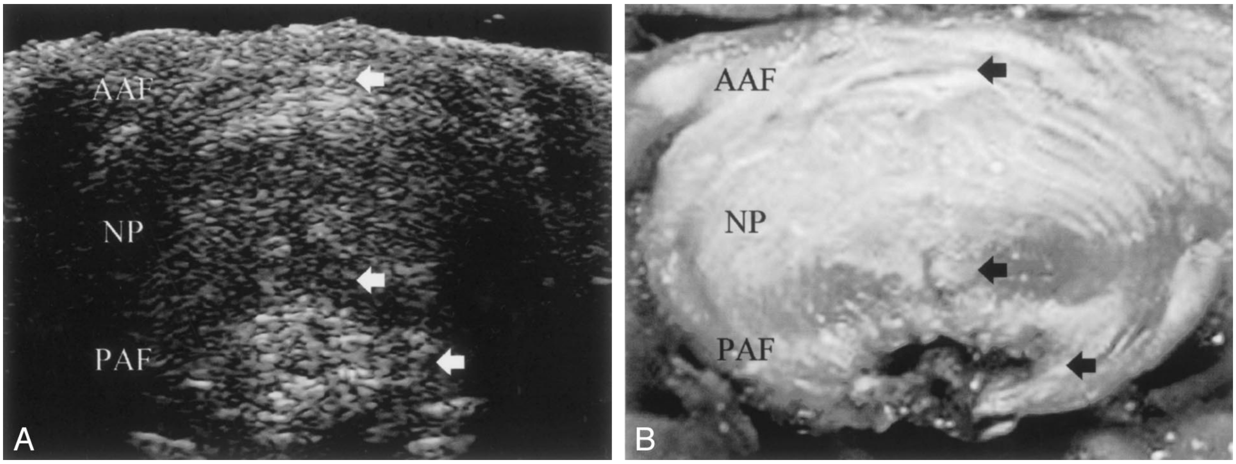

Figure 4. **A,** Ultrasonic image of an intervertebral disc. Arrows indicate the positions of gross pathologic defects. **B,** Photographic image of the intervertebral disc pictured in **a.** Arrows indicate the positions of gross pathologic defects.

It must be noted that in this study only one ultrasound machine operator was used, and only one observer assessed the ultrasound images. This was considered to be acceptable for the purposes of a scientific study to keep variability to a minimum. Interobserver, intraobserver, interoperator, and intraoperator reliability all must be considered in future studies if this method of disc imaging is to become widely accepted.

Detection of Specific Pathologic Defects

The correlation between the appearance of an abnormality on the ultrasound image and the presence of an actual gross pathologic defect was extremely high in this study. All the gross defects identified on the photographic images of the discs also were identified on the ultrasonic images (Table 4). A number of unmatched results also were recorded. In these cases, the appearance of a defect on the ultrasonic image was not confirmed by the photographic appearance of the disc.

Some of these cases yielded genuine false-positive results, as shown, for example, in Figure 5. The ultrasound image displayed in Figure 5 shows a hyperechoic outline around the nucleus pulposus of the intervertebral disc. Further investigation showed that this particular disc came from a relatively immature subject (6 months old) with an extremely fluid and well-hydrated nucleus pulposus. Therefore, the bright reflection may have been caused by a large mismatch in the acoustic impedance between the anulus and the nucleus rather than a tissue defect. Information regarding the age of the specimen at the time of scanning would prevent false-positive results of this nature.

In other cases wherein defects identified on the ultrasound and photographic images did not match, the reasons were unclear. For example in the case shown in Figure 6, there appears to be a focal increase in echo levels toward the posterior of the anterior anulus fibrosus and in the central region of the nucleus (indicated by arrows). During assessment of the photographic images, the observer made no reference to pathologic changes in these regions.

The increase in echoes in the apparent absence of a defect may occur for several reasons. The echoes may arise as a result of a section thickness artifact. The photographic image has no thickness, whereas the ultrasound image is derived from three-dimensional information compressed in the direction perpendicular to the beam to give a two-dimensional image. This is because

Table 4. The Number of Specific Pathological Defects (e.g., Circumferential Tears, Nuclear Fissures) Identified in Each Area of the Disc

	Imaging Modality	
Location of Pathologic Defect	Photography	Ultrasound
Anterior annulus fibrosus	8	9
Nucleus pulposus	7	10
Posterior annulus fibrosus	3	3

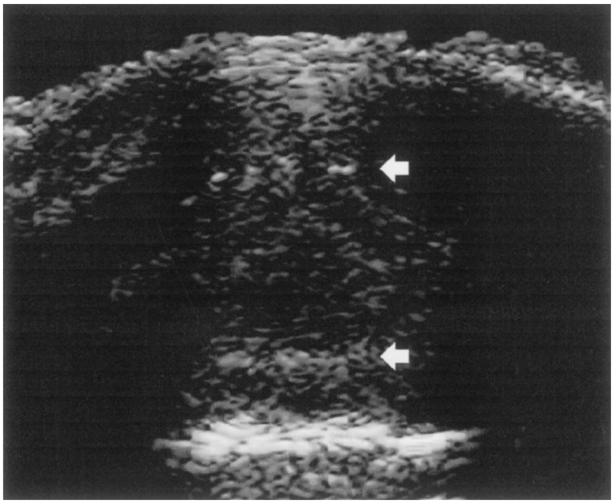

Figure 5. Ultrasonic image of an intervertebral disc taken in the transverse plane. Arrows indicate the bright echoes originating at the border of the nucleus pulposus.

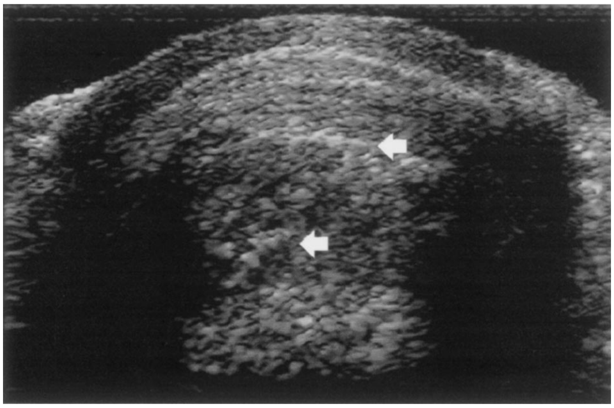

Figure 6. Ultrasound image of an intervertebral disc. Arrows indicate the positions of increased echo levels.

the ultrasound beam has a width perpendicular to the scan plane. Echoes are received that originate not only from the center of the beam, but also from off center. These are all collapsed into a thin, two-dimensional image, and can result in the appearance of false debris in echo-free areas. The increased region of echoes may therefore originate genuinely from a defect or alteration in the disc structure, but in a region above or below the point at which transection of the disc was performed.

It is possible that ultrasound is sensitive to the early changes associated with the development of pathologic defects. Identification of pathologic defects based on the appearance of relatively low-magnification photographic images requires the defect to be well advanced in development before it can be detected.

Ultrasound is sensitive to changes in the mechanical properties of tissues. The intensity of a reflection depends on the incident intensity and the impedances of the media at the boundary. Impedance is determined by the density and stiffness of a medium. The greater the difference in the impedances of two adjacent tissues, the higher will be the intensity of the reflection occurring at their boundary. If large enough changes in tissue stiffness or density occur before changes in the visual appearance of the disc, ultrasound will display the changes while photographic images appear normal. Further work is required to determine whether this is the case or not.

Little is known about the diagnostic sensitivity of ultrasound with regard to intervertebral disc tissue. The results from the second section of this study indicate that ultrasound detected more pathologic changes in disc structure than were detectable from the photographic images. Whether the additional changes detected through ultrasound are early signs of degeneration, an artifact, or the result of sensitivity to normal nondegenerative changes in factors such as hydration is yet to be determined. What is clear from this simple initial study is that ultrasonic images of intervertebral discs relate well to the general pathologic condition of the discs. In addition, ultrasound images demonstrate specific focal pathologic defects.

Whether this technique for grading the pathologic condition of the disc can be applied *in vivo* is dependant on the attenuating effect of the tissue through which the ultrasound beam must pass to reach the intervertebral disc. McNally *et al*[9] have demonstrated that it is possible to obtain images of the intervertebral disc *in vivo* using two different approaches at 3.5 MHz: (1) placing the transducer on the surface of the back and directing the ultrasound beam through the muscles of the back or (2) using a transabdominal approach. Whether the images obtained contain sufficient information to enable grading of their pathologic condition requires further investigation. New systems using digitally encoded ultrasound enable images with the resolution of a 7-MHz transducer to be at a depth of 18 cm and beyond. Such systems should facilitate the acquisition of images containing a sufficient degree of structural information from the intervertebral discs *in vivo*.

Imaging of pathologic intervertebral discs is a potential application of ultrasound, which so far has remained largely unexplored. As it stands, this technique is suitable for applications such as screening explanted intervertebral discs for defects before mechanical testing or other experimental work. Further work is required to determine the full range of pathologic defects detectable through ultrasound, their significance in back pain, and the possible application of this technique *in vivo*, including comparisons with other imaging techniques.

■ Key Points

- Imaging of pathologic intervertebral discs is a potential application of ultrasound, which so far has remained largely unexplored.
- The ultrasound grading scale was shown to be a reliable method for use in the assessment of disc degeneration, based on ultrasonic appearance. Ultrasound images of intervertebral discs relate well to their pathologic condition.
- The correlation between the appearance of a focal abnormality on the ultrasound image and the actual presence of a specific gross pathologic defect appears to be extremely high.

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