Quantitation of Galactosemic Cataracts in Dogs Using Magnetization Transfer Contrast-Enhanced Magnetic Resonance Imaging

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Purpose. Magnetic resonance imaging (MRI) is becoming increasingly important for the diagnosis and characterization of ocular pathologies. A drawback to this technique is that image contrast between different regions of tissue can be obscured because of the similarity of their nuclear magnetic resonance relaxation parameters. This problem is addressed by magnetization transfer contrast (MTC) enhancement, a MRI technique that generates high-contrast images based on characteristic tissue differences resulting from the interaction of water and macromolecules. The purpose of this study was to investigate the feasibility of using MTC-enhanced imaging to monitor quantitatively the lens changes associated with sugar cataract formation in galactose-fed dogs.

Methods. Male beagles fed a diet containing 30% galactose were periodically examined by MRI for changes in tissue character. Each examination included a gradient recalled echo image (Mr), an MTC-enhanced gradient recalled echo image (Ms), a T1 image determined from a one-shot T1 imaging sequence, and a T1-weighted image taken from the raw T1 data. Average values were obtained for several regions of interest and tabulated. These were correlated with cataractous stages visually observed by slit lamp biomicroscopy and retroillumination photography.

Results. Enhanced image details of the lens and anterior segment that documented osmotic changes from initial cortical vacuole formation to cortical and nuclear changes associated with advanced sugar cataracts were characterized from measurements of parameters obtained from Mr, Ms, T1-weighted, and T1 images. Changes in the cross-sectional areas of lenses during sugar cataract formation also were documented. The magnetic resonance images showed visible changes from the onset of cortical vacuole formation. Region of interest (ROI) analysis of the images showed tissue changes occurring throughout the cataract progression.

Conclusions. The MTC-enhanced MRI technique is well suited to detecting lens changes associated with cataractogenesis. All but the earliest changes were readily apparent from the images with no further analysis. Graphic ROI analysis was able to detect regional changes associated with the cataract progression for all degrees of severity. Furthermore, the images demonstrated changes in size and shape that would not be detectable by visual inspection. Invest Ophthalmol Vis Sci. 1996;37:2219–2227.

The galactose-fed dog develops diabetes-like ocular complications, such as keratopathy, retinopathy, and cataract formation. Sugar cataract formation is linked to the increased formation of sugar alcohols (polyols) from glucose or galactose that are catalyzed by the enzyme aldose reductase. Polyol accumulation leads to osmotic imbalances, which result in lens swelling and subsequent changes in membrane permeability. The initial stages of cataract formation, which include suture accentuation and the formation of cortical vacuoles, are reversible, but the later stages, when total cortical opacities, nuclear opacities, or liquefaction occur, are not. In osmotic cataract formation, localized biochemical changes have been detected by magnetization transfer contrast (MTC) enhancement magnetic resonance imaging. The MTC technique uses water-macromolecule interactions to generate in-
creased contrast in magnetic resonance (MR) images. With this technique, differences in the composition and hydration of tissues can be distinguished by their altered intensities in the MR image. Water protons and macromolecular protons make up two of the major components of a tissue nuclear magnetic resonance spectrum. The water protons resonance is narrow (~20 Hz) because of the water molecules' rapid motion, whereas the macromolecular proton resonance is broad (>10 kHz) because of its immobile nature. For most MR images, signal from the macromolecular protons is dispersed before signal acquisition begins so that the resultant MR image represents signals caused solely by the bulk water protons. In an MTC experiment, macromolecular proton signals are saturated with a narrow-band, off-resonance irradiation. This saturation is transferred by dipolar coupling to water protons located in the hydration layer on the tissue macromolecules and then by physical exchange of the water molecules to the bulk water protons. The degree of magnetization transfer is dependent on the degree of saturation of the macromolecular protons, the strength of the dipolar coupling at the macromolecule surface, and the rate of exchange of water molecules located between the hydration layer and the bulk (free) water. These quantities are sensitive to changes in the local microscopic environment. Magnetization transfer can be modeled as the interaction of two varying reservoirs of spins. One reservoir is composed of hydrogens on the bulk water molecules and other highly mobile molecules. The second reservoir of magnetization is composed of hydrogens attached to tissue macromolecules. Each reservoir can be characterized by longitudinal and transverse relaxation times $T_1$ and $T_2$. For the macromolecular proton reservoir, $T_{1M}$ describes the length of time an $rf$ saturation will last, and $T_{2M}$ describes the distribution of macromolecular proton frequencies. Larger values of $T_{1M}$ result in longer periods of magnetization transfer before equilibration and result in more saturation. Smaller values of $T_{2M}$ increase the rate of magnetization transfer. Neither $T_{1M}$ nor $T_{2M}$ is measurable using in vivo MR imaging techniques. In this context, the bulk relaxation parameters $T_1$ and $T_2$ have their usual meanings.

Other lens studies using nuclear magnetic resonance or magnetic resonance imaging have focused on parameters such as the longitudinal relaxation time $T_1$, the transverse relaxation time $T_2$, and the diffusion constant $D$ of bulk (free) water. Although some insight into the mechanism of cataractogenesis has been gained by these techniques, they are not readily applicable in vivo. This is because the signal averaging time required for a useful image can be prohibitive, radio frequency power deposition can become too high, some of the magnetic resonance imaging pulse sequences are sensitive to pulse parameter errors, and time consuming post processing may be required. In contrast, MTC enhancement can be implemented directly and incorporated into many rapid imaging experiments. The increase in radio power deposition required for MTC is minimal, and tissue property variations can be assessed from the acquisition of a single image. The feasibility of MTC imaging to monitor in vivo lens changes in galactose-fed dogs has been reported recently to document osmotic changes ranging from initial cortical vacuole formation to cortical and nuclear changes associated with advanced sugar cataracts, the latter of which could not be observed by photo-slit lamp or retroillumination photography. Here we extend the observation that the MTC technique offers a simplified method for monitoring cataractous changes by demonstrating that all stages of sugar cataract formation in dogs can be characterized by parameter measurements obtained from $M_t$, $M_{0t}$, and $T_1$ images.

**MATERIALS AND METHODS**

All studies conformed to the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research. Groups of five male beagles obtained at either 6 or 24 months from Marshal Farms USA Inc. (North Rose, NY) were individually housed and fed standard dog chow diet containing 30% galactose (Bioserve, Frenchtown, NJ) as previously described. Lens changes in these dogs were compared to control age- and sex-matched beagles fed standard dog chow. All dogs were examined weekly for lens changes by slit lamp biomicroscopy. Before examination, mydriasis was induced using 1% tropicamide hydrochloride. Cataract severity was classified according subjectively to the presence of anterior and posterior suture accentuation, fine cortical vacuole formation around the cortex and suture ends, dense cortical opacities, dense cortical opacities with the formation of a peripheral cortical clear zone, and dense cortical opacities with nuclear involvement.

Each dog was examined by proton MR imaging at 4-week intervals in a 2-Tesla magnet using a General Electric Omega spectrometer (Bruker Instruments, Billerica, MA). The dogs were sedated with intramuscular injections of acepromazine (2.5 to 5 mg/kg), intubated, ventilated with a 1.5%–58.5%–40% halothane–nitrous oxide–oxygen mixture, and eye movement was minimized by the administration of succinyl choline at a rate of 40 to 50 ml/hour (200 mg/250 ml 0.9% salt solution). Each dog was positioned in a molded cradle, and a single turn surface coil (48 mm diameter) was positioned over the eye.

Oblique images were acquired through a plane containing the optic axis and equatorial regions. Two perpendicular scout images were acquired initially, and measurements of the lens axes and were used to calculate the appropriate oblique plane. This pro-
vided a method for reliably reproducing each slice position. For each imaging session, a standard gradient recalled echo image (\(M_0\)), a gradient recalled echo image with saturation (\(M_s\)), and a set of eight images (IR) from a one-shot imaging sequence that applied an inversion pulse and sampled the recovering magnetization every 0.5 second with a small flip angle (<25°) pulse was obtained. The saturation consisted of \(1 \times 10^{-5}\) Tesla \(\gamma\) irradiation 10 kHz off resonance from the water peak. The \(\gamma\) irradiation was calibrated by measuring the flip angle in a reference sample attached to the MRI probe. The imaging parameters used were NA = 4; TR = 2 seconds; TE = 20 msec; FOV = 50 mm; 2 mm slice thickness; and 256 X 128 phase encodes image size. The single slice acquisition time was 20 minutes. IR images were used to calculate a pixelwise T1 image by fitting the relaxation curve to a recovering exponential equation. All calculations were performed on a Sun workstation using routines written for Interactive Data Language (Research Systems, Boulder, CO) using the least squares method. The IR image at 1 second was used as a T1-weighted image.

Because of changes in the size and shape of the lens observed during cataract formation, a standardized region of interest (ROI) (e.g., a fixed-size square or circle) was difficult to implement. Instead, an irregularly shaped region was defined using a mouse-based computer routine. The nuclear region was traced while care was taken not to include any points in the cortex. The anterior cortex was traced while taking care not to include any nuclear or equatorial regions. The average intensity for each region was determined by summing the pixel intensities in any ROI and dividing by the number of points. The same region was used for each image in a set (\(M_0, M_s, M_s/M_0, T_1, T_1\) weighted). All analyses were performed using routines written for Interactive Data Language. Composite progressions for each parameter were formed by averaging over each dog lens at the same degree of cataract severity, resulting in a graph of five (older dogs) or six (younger dogs) points. Error bars represent the standard error of the mean.

RESULTS
Sugar cataract formation was induced in 6- and 24-month-old beagles through 30% galactose feeding. For each dog, lens changes were monitored weekly by slit lamp biomicroscopy, and these were correlated with proton MR lens images obtained at 4-week intervals in a 2-Tesla magnet using a General Electric Omega spectrometer. For the MR images, preliminary scout images were used to calculate exact oblique imaging planes so that the same cross-section could be followed. Preliminary reports of lens changes have been reported elsewhere.

Magnetic Resonance Imaging Studies
The appearance of anatomic features of the cornea, iris, lens nucleus, and lens cortex in a standard, unsaturated (\(M_0\)) image of the normal dog eye are illustrated in Figure 1A. When the image is acquired with saturation (\(M_s\)) (Fig. 1B), additional anatomic features such as the lens epithelium become evident, and increased detail in the ciliary body can be observed.

The contrast-to-noise ratio, relative to the nucleus, was measured for several ROIs and for several differ-
ent imaging modalities (Table 1). The contrast-to-noise ratio, $\Delta S$, is defined by

$$\Delta S = \frac{I_{\text{ROI}} - I_{\text{unc}}}{N}$$

where $I_{\text{ROI}}$ is the average intensity of the ROI, $I_{\text{unc}}$ is the average intensity of the nucleus, and $N$ is the background noise intensity. This is a convenient method for quantitatively distinguishing between two types of tissue while adjusting for image quality. Small values of $\Delta S$ between two regions indicate either that the data are insufficient for making a distinction between the two regions or that there is no significant difference. Values of the contrast-to-noise ratio, $\Delta S$, obtained for the aqueous, anterior cortex, equatorial cortex, posterior cortex, and vitreous in $M_o$, $M_s$, $T_1$, and $T_2$-weighted images are summarized in Table 1. The apparent uniformity of the relaxation properties of water in various regions of the lens made differentiation of lens tissues more difficult. The best differentiation was always obtained with gradient-recalled echo images. Due to partial-volume effects that artificially increased the affected area and reduced the net effect on individual pixels, the $M_s$ images that were not observed in dogs in which cataracts did not develop were indistinguishable from those of normal lenses. The osmotic swelling and new fiber differentiation in the equatorial regions of the lens was higher contrast-to-noise values.

Typical MR images of cataract progression from the onset of suture accentuation through the mature cataract stage are illustrated in Figure 2. The MR images of a lens with suture accentuation (row 1) were indistinguishable from the MR images of a normal dog lens. This is because the subtle biochemical changes responsible for suture accentuation only affected a small area of each image. Detection of the early changes was complicated further by partial volume effects that artificially increased the affected area and reduced the net effect on individual pixels.

As fine vacuole formation began (Fig. 2, row 2), the $M_o$ and $T_1$-weighted images remained indistinguishable from those of normal lenses. The $M_s$ and $T_1$ images showed inhomogeneities at the equatorial regions (arrows) that corresponded to the fine cortical vacuoles. The vacuoles are filled primarily with liquid, so that the MTC effect in these regions was reduced. Because of image resolution and diffusion effects, individual vacuoles were not apparent.

Only when the entire cortex of the lens was affected (Fig. 2, row 3) did all of the MR images show the effects of the progressing cataract. The anterior cortex of the lens showed substantial inhomogeneity because of hydration variations in the cortical opacities. The MTC effect in the posterior cortex was increased despite the lack of vacuole formation. Meanwhile, the MTC effect in the equatorial regions decreased and contrast was reduced. Cataractous changes were observed most clearly in the $M_s$ image.

Lens changes continued to be apparent during the formation of the cortical clear zone (Fig. 2, row 4) in which a laminar appearance in lens images was observed. As the cataract progressed, successively deeper layers of the lens became affected. Low-magnetization transfer appeared in the equatorial regions of the lens, an area corresponding to an area in which new lens fibers are laid down to form the clear zone. Because the MTC effect is smaller in this region than in healthy lens cortex, it implies that these lens fibers are not normal. The osmotic swelling and new fiber formation contributed to the swollen appearance of the lens.

For the younger dogs only, the cataract became fully mature (Fig. 2, row 5). The image of the lens appeared swollen compared to the original lens. Contrast in the $M_o$ image was noticeably poorer. The osmotic integrity of the lens tissue appeared to be compromised completely, with water concentration across the lens appearing almost uniform. Laminar structures that appeared during the formation of the cortical clear zone remained and corresponded to suture separation and hydration differences between the different layers. 

### Quantitation of Cataractous Changes in MR Images

**Cross-Sectional Area.** Along with the biochemical changes and tissue hydration affecting only the relaxation parameters, changes in lens size and shape were observed in the MR images during cataractogenesis that were not observed in dogs in which cataracts did not develop.

**TABLE 1. Summary of Contrast-to-Noise Ratio ($\Delta S$) for Several Different Regions of Interest and Several Different Imaging Techniques**

<table>
<thead>
<tr>
<th>Region</th>
<th>$M_o$</th>
<th>$M_s$</th>
<th>$T_1$</th>
<th>$T_2$-Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueous</td>
<td>10.3 ± 1.5</td>
<td>15.2 ± 1.3</td>
<td>2.4 ± 0.3</td>
<td>3.0 ± 0.5</td>
</tr>
<tr>
<td>Anterior cortex</td>
<td>20.5 ± 1.5</td>
<td>8.4 ± 1.9</td>
<td>0.5 ± 0.3</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Equatorial cortex</td>
<td>19.3 ± 3.3</td>
<td>10.8 ± 2.0</td>
<td>0.7 ± 0.1</td>
<td>3.3 ± 0.6</td>
</tr>
<tr>
<td>Posterior cortex</td>
<td>13.7 ± 1.3</td>
<td>7.4 ± 1.5</td>
<td>1.1 ± 0.6</td>
<td>1.7 ± 0.6</td>
</tr>
<tr>
<td>Vitreous</td>
<td>10.3 ± 1.5</td>
<td>15.2 ± 1.3</td>
<td>2.4 ± 0.3</td>
<td>3.0 ± 0.4</td>
</tr>
</tbody>
</table>
FIGURE 2. Summary of magnetic resonance images from various dogs during the progression of sugar cataract. (top to bottom) Images correspond to suture accentuation, cortical vacuoles, anterior opacity, clear zone, and mature cataract, respectively. (left to right) Images correspond to $M_0$, $M_s$, $T_1$ weighted, and $T_1$, respectively.

not form. Because the cross-section of lens area examined was reproduced reliably, the observed size changes were caused by cataractogenesis. The lens cross-sectional area was measured using ROI analysis. The perimeter of the lens was traced and the area within the perimeter was computed. Figure 3 illustrates changes in cross-sectional areas during sugar cataract formation for lenses from the older 2-year-old dogs versus the younger 6-month-old dogs. Maximum lens area occurred just after the formation of the cortical clear zone. In all dogs progressing either to this stage or further, the maximum change was approximately 10%. In the younger dogs, changes in lens size were more pronounced. A decrease in lens size more pronounced than in the older dogs initially occurred, and this was followed by an increase and then a decrease in lens size. The reason for these initial size fluctuations is unclear. A decrease in intracellular volume that is suppressed or bypassed in the older beagles is one possibility. The subsequent increases can be attributed to osmotic swelling (younger dog lenses gain more than older), and the eventual decrease in size can be attributed to resorption–liquefaction of lens fiber proteins and potential fluid loss associated with altered cell membrane integrity. Further biochemical studies are required to determine the exact relationship between the observed variations in cross-sectional area and overall lens volume and shape changes.

Characterization of Tissue Changes

For each imaging technique, a composite time course was constructed for both groups of dogs by computing an average time of onset for each degree of cataract
formation and an average of the average intensities for each ROI in the affected dogs. A contrast-to-noise ratio, relative to the aqueous, was calculated from these data according to the equation:

$$\Delta S_{\text{AQ}} = \frac{I_{\text{ROI}} - I_{\text{AQ}}}{N}$$

where $I_{\text{AQ}}$ is the average intensity of the aqueous chamber. The aqueous was used as a convenient internal standard to assess lens changes because it is primarily fluid. Because the aqueous is primarily fluid, its MR parameters should be unaffected by potential small composition changes occurring during cataractogenesis. No correction was performed for $B_1$ inhomogeneity. The ROIs are geographically close and are located in a region in which the variation is no more than 10%. The error caused by biologic variation is much larger.

**M$_0$ Progression**

In the older dogs, sugar cataract formation was observed to progress from initial suture accentuation to the formation to vacuoles, cortical opacities, and eventually superficial equatorial cortical clearing. In the younger dogs, sugar cataract formation has been seen progressing from initial suture accentuation to the formation to vacuoles, cortical opacities, and finally mature cataracts with nuclear involvement. The $\Delta S_{\text{AQ}}$ values for the older dogs remained relatively constant, with the largest deviation occurring during vacuole formation (Fig. 4). In contrast, larger changes in contrast were observed in the younger dogs, with the biggest effect occurring during the earliest stages of cataract formation. In general, contrast appeared to decrease until the cataract was fully mature. (Smaller absolute values of $\Delta S_{\text{AQ}}$ indicate less contrast.) Changes in contrast observed with the unenhanced MR imaging technique are caused solely by a combination of changes in tissue hydration and the transverse relaxation time of the bulk hydrogen magnetization ($T_2$). Contrast values decrease with shorter $T_2$ values and increase with more tissue hydration. For the older beagles, the slower changes occurring in the $M_0$ contrast graphs suggest that hydration and $T_2$ vary slowly. Several researchers have demonstrated that hydration and $T_2$ in lens tissue are correlated directly$^{15-17}$; hence, it appears unlikely that decreases in $T_2$ compensate for increased hydration. Decreasing contrast values of the younger beagles agree with the model of increasing hydration accompanying polyol accumulation and osmotic breakdown. It is evident from these data that nuclear changes occur despite its clear appearance.

**$M_0$ Progression**

Despite the decreased signal-to-noise ratio, the $\Delta S_{\text{AQ}}$ values from the older dogs show a steady decrease throughout cataract progression (Fig. 5). The $\Delta S_{\text{AQ}}$ values from the younger dogs show a similar progression to $M_0$, with stronger contrast. After suture accentuation, a similar progression was observed in both

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**FIGURE 3.** Progression of lens cross-sectional area for an old dog (circles) and a young dog (diamonds).

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**FIGURE 4.** Composite progression of $M_0$ contrast-to-noise ratio $\Delta S_{\text{AQ}}$ for old (A) and young (B) dogs. Nucleus (triangles), cortex (circles), and equatorial region (squares).
groups of dogs. The MTC technique allows clearer observation of cataractous changes occurring in the lens, particularly in the older dogs. As the $M_0$ contrast values decrease over time, the $M_s$ contrast tends to increase. The increased slope in the $\Delta S_{Aq}$ graph is caused by the increasing interaction between the pools of proton magnetization. This is caused by a combination of several physical effects. Increased hydration yields more water molecules in the hydration layer, which can absorb macromolecular saturation to be transferred to the bulk water molecules. As the osmotic barriers fail, the water molecules have greater access to saturated macromolecular tissue. Additionally, the magnetization transfer rate between the pools of magnetization may be changing.

$T_1$-Weighted Progression

A composite time course was constructed from the $T_1$-weighted images for both groups of dogs (Fig. 6). Although changes with severity of cataract were observed in both groups, the magnitude of these changes between the different stages was smaller than those observed for either the $M_0$ or the $M_s$ progression. This suggests that $T_1$-weighted time course data are less useful than the corresponding $M_0$ or $M_s$ data.

DISCUSSION

Sugar cataract formation in galactose-fed dogs has been documented in 6-, 9-, and 24-month old beagles. The rate of formation and the severity of lens changes is age dependent, with more rapid and severe
cataracts appearing in younger dogs. In the 9- to 24-month-old dogs, sugar cataract formation begins with an accentuation of anterior and posterior lens sutures. This is followed by the appearance of cortical vacuoles and the formation of cortical opacities predominantly equatorial toward the posterior cortex. Finally, a progressive, irregular clear zone forms at the periphery of the cortex. In 6-month-old dogs, in which cataract formation was more rapid and severe, lens changes in some dogs progressed from the formation of dense cortical opacities and large posterior vacuoles to mature cataracts with nuclear involvement.

Using MR imaging techniques, cataractogenesis can be documented easily without concern for nonvisible parts of the lens—for example, cortical tissue behind the iris or lens tissue behind anterior cortical opacities. Additionally, structural changes in the lens can be observed that are not measurable using any optical technique. Some of these changes are visible on conventional MR images but are clearer in the MTC-enhanced images. The MTC-enhanced images are able to show early cortical changes but not suture accentuation. Because image analysis shows a steady progression of changes, it is possible that suture accentuation may be detectable on an image with higher resolution. This would reduce the partial volume effects at the cost of increased imaging time (for the same signal-to-noise ratio).

Quantitative analysis of the MR images provided an objective measure of cataract progression. Because the entire lens was visible, physical parameters could be measured and compared. A cross-sectional lens area provided a straightforward measure that could be obtained with any of the imaging methods. The T<sub>1</sub> or M<sub>T</sub> image was the best image for measuring the lens areas because of the clear demarcation between the lens and the surrounding tissues. Presumably, a non-linear display scale could be used to bring out the demarcation in the M<sub>T</sub> image, but this would increase the amount of post-processing required and would obscure other parts of the image.

Hydration and biochemical changes could be assessed by analyzing intensity changes in the MR images. The image changes correspond well with hydration changes, but the amount of hydration change cannot be calculated easily from the images because altered intensity could be caused in part by slowly varying magnetization relaxation times. Along with hydration changes, an altered T<sub>2</sub> could be responsible for some of the intensity changes. These two effects cannot be separated on any one image. The contrast-to-noise ratio was chosen as the measurement parameter because it is sensitive to small changes in the signal intensity and it compensates for potential gain variation in different images. Region of interest analysis of the MR images was able to detect and follow cataractous changes. Quantitative evaluation of the M<sub>T</sub> and M<sub>T</sub> detected small changes in the lens tissue; however, the MTC-enhanced images were the most sensitive measure of cataract severity. The longitudinal relaxation time, T<sub>1</sub>, was not a useful measure until late in the cataract progression.

**CONCLUSIONS**

Using the magnetization transfer contrast-enhanced magnetic resonance image technique, high-definition images of the lens and ocular body, with good contrast between different types of tissue, can be generated. MTC-enhanced MR images appear to detect all but the most subtle changes associated with sugar cataractogenesis. Moreover, the MR images demonstrate changes in lens size and shape that are not detectable by more conventional means. Size changes correlate well with the degree of cataract formation.

Quantitative evaluation of cataract severity is possible using ROI analysis. ROI analysis of the lens images demonstrates even the earliest change of suture elongation occurring during sugar cataractogenesis, before cor-
tical vacuole formation. Unlike diffusion imaging or T₂ imaging, this result can be accomplished with the acquisition of only one image (Mₛ). Despite the decreased signal-to-noise ratio because of saturation, the Mₛ images are the most sensitive to changes in hydration and magnetic relaxation properties in the tissue. The additional interaction provided by the magnetization transfer allows increased detection of cataractous processes if the changes in hydration and relaxation parameters are small.

The MTC enhancement is a simple alteration that can be added easily to almost any MR imaging sequence. Adding MTC enhancement to a rapid imaging technique (e.g., FLASH) presents a feasible method for applying MR imaging of cataracts in a clinical setting. In this way, an image can be obtained in a few seconds.¹⁸ Analysis of the MTC images presents a feasible method of characterizing lens changes.

**Key Words**
cataract, dog, lens, magnetic resonance imaging (MRI), magnetization transfer contrast (MTC)

**References**