Development of a Surface Marker for Fractional Anisotropy Maps Using Wood in a Phantom Study

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Purpose: To improve imaging, a reliable setup method is critical for the accurate localization of lesions and surface markers. Because an anisotropic marker has not yet been validated for MRI, direct localization of surface markers is not yet feasible in fractional anisotropy (FA) maps. This study aimed to develop an anisotropic surface marker using wood for an FA map and to determine whether a wood marker is useful for various sequences.

Methods: Wood infiltrated with water was used to develop an anisotropic surface marker. The wood marker was compared with phantoms composed of clinically available markers, including MR-SPOTS Packets (Beekley Medical, Bristol, CT, USA), Breath Care Oral Refreshing Capsules (Kobayashi Pharmaceutical Co., Ltd., Osaka, Japan), and baby oil (Johnson & Johnson, New Brunswick, NJ, USA). Magnetic resonance images were acquired using the Achieva 3T TX MRI System (Philips HealthCare, Best, Netherlands) equipped with a QD head coil including T₁- and T₂-weighted imaging, proton-density-weighted imaging, T₂*-weighted imaging, T₁-weighted imaging spectral pre-saturation with inversion recovery, T₂-weighted imaging spectral attenuated inversion recovery, proton-density-weighted imaging spectral attenuated inversion recovery, diffusion weighted imaging, and diffusion tensor imaging. Apparent diffusion coefficient, FA values, and signal-to-noise ratio (SNR) were measured and recorded, and the coefficient of variation was calculated for two consecutive imaging scans. The wood was observed using a microscope.

Results: Breath Care Oral Refreshing Capsules and baby oil were not observed in the FA map. The FA value of the MR-SPOTS Packets was 0.18. The FA value of the wood marker was 0.80. The coefficient of variation of the MR-SPOTS Packets and the wood marker were 0.0263 and 0.0013, respectively, in the FA map. Microscopic observation revealed a wood anisotropic structure.

Conclusion: The wood maker enabled direct localization in the FA map. Hence, wood markers may be useful to radiologists and contribute to obtaining useful findings.

Keywords: diffusion tensor imaging, fractional anisotropy map, skin marker, surface marker

Introduction

Surface markers are used in MRI¹ to identify the location of masses and sites of pain. The markers can be attached to a reference point to designate the location of a target site in clinical findings, which are difficult to observe without a suitable marker for interpreting radiological images as they may not be observed on imaging. Therefore, radiological technologists use markers over sites of symptoms or palpable masses before examinations. The markers are useful to radiologists in interpreting findings.

However, very few studies have examined conventional surface markers in various MRI sequences. Itoh et al.⁴ investigated Breath Care Oral Refreshing Capsules (Breath Care; Kobayashi Pharmaceutical Co., Ltd., Osaka, Japan), which are inexpensive and readily available. Ebrahimi et al.⁵ used MR-SPOTS Packets (MR-SPOTS; Beekley Medical, Bristol, CT, USA), which are commercially available markers. Takatsu et al.⁶ suggested that even baby oil can be used to localize lesions in MRI.

Manganese chloride capsule markers have been used to localize lesions in T₁-weighted imaging (T₁WI) and in comparisons with diffusion tensor imaging (DTI).⁷ The absence of useful markers for DTI required T₁WI acquisition and a

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comparison of images. Moreover, such comparisons would be impossible when imaging is not performed in the same direction.

The development of novel surface markers may lead to an improved interpretation of DTI findings. We performed a pilot study to verify the anisotropy of wood infiltrated with water through the tracheid. Our study aimed to develop a surface marker for DTI made from wood infiltrated with water, and to verify whether a wood marker is useful for various sequences in MRI. To date, a surface marker useful for DTI has not yet been made available. However, such a novel wood marker would be effective and enable direct localization for DTI purposes.

Materials and Methods

Phantom

MR-SPOTS, Breath Care, baby oil (Johnson & Johnson, New Brunswick, NJ, USA), and the wood marker (Chamaecyparis obtuse) were used as phantoms. MR-SPOTS, Breath Care, and baby oil have been previously used in research and the clinic. Chamaecyparis obtuse was provided by the Forestry and Forest Products Research Institute for use in this study.

Breath Care-, MR-SPOTS-, and baby oil-filled 5 mL syringes were used in the present study. A piece of dry wood, $14 \times 14 \times 40 \text{ mm}^3$ in size, was boiled for 20 min and stored in a water-filled container for 7 days. The wood specimen was sealed in a polypropylene case using vinyl tape. The wood piece and other syringes were secured in the same polyvinyl alcohol-filled container (Fig. 1).

Imaging

Images were acquired using an Achieva 3T TX MRI System (Philips HealthCare, Best, The Netherlands) equipped with a QD head coil. Protocols and measurement parameters were as follows and are summarized in Table 1. Protocols included SURVEY: fast field echo; TE $4.6 \text{ ms}$; TR $9.8 \text{ ms}$; flip angle $15^\circ$; scan time 16 s; T$_1$WI: spine-echo; TE $10 \text{ ms}$; TR $600 \text{ ms}$; scan time 2 min 56 s; T$_2$-weighted imaging (T$_2$WI): turbo-spin-echo; TE $100 \text{ ms}$; TR $3000 \text{ ms}$; scan time 2 min 25 s; proton-density-weighted imaging (PDWI): turbo-spin-echo; TE $30 \text{ ms}$; TR $3500 \text{ ms}$; scan time 2 min 25 s; T$_2^*$-weighted imaging (T$_2^*$WI): fast field echo; TE $9.2 \text{ ms}$; TR $500 \text{ ms}$; flip angle $25^\circ$; scan time 2 min 25 s; T$_1$WI spectral pre-saturation with inversion recovery (SPIR): spine-echo; T$_2^*$WI: spectral attenuated inversion recovery (SPIR): spine-echo.

![Phantoms, left to right: 5 mL syringes filled with MR-SPOTS Packets (Beekley Medical, Bristol, CT, USA), Breath Care Oral Refreshing Capsule (Kobayashi Pharmaceutical Co., Ltd., Osaka, Japan), baby oil (Johnson & Johnson, New Brunswick, NJ, USA), and the water-infiltrated wood marker in the same polypropylene case. All markers are in a polyvinyl alcohol filled phantom container.](image-url)

Table 1 Imaging parameters

| Parameter          | TE (ms) | TR (ms) | FA (°) | FOV (mm × %) | Matrix | Slice thickness (mm) | Slice gap (mm) | Averages | BW (Hz) | Scan time |
|--------------------|---------|---------|--------|--------------|--------|----------------------|----------------|----------|---------|-----------|
| Survey (FFE)       | 4.6     | 9.8     | 15     | 250 × 100    | 256    | 10                   | 1              | 1        | 124.3   | 0:16      |
| T$_1$WI (SE)       | 10      | 600     | 90     | 170 × 75     | 256    | 4                    | 1              | 3        | 163.3    | 2:56      |
| T$_1$WI (TSE)      | 100     | 3000    | 90     | 170 × 75     | 256    | 4                    | 1              | 3        | 106.0    | 2:00      |
| PDWI (TSE)         | 30      | 3500    | 90     | 170 × 75     | 256    | 4                    | 1              | 3        | 289.7    | 2:30      |
| T$_1$WI (FFE)      | 9.2     | 500     | 25     | 170 × 75     | 256    | 4                    | 1              | 2        | 217.0    | 2:25      |
| T$_1$WI SPIR       | 10      | 600     | 90     | 170 × 75     | 256    | 4                    | 1              | 1        | 196.4    | 3:15      |
| T$_1$WI SPAIR      | 100     | 3000    | 90     | 170 × 75     | 256    | 4                    | 1              | 4        | 106.0    | 2:39      |
| PDWI SPAIR         | 30      | 3500    | 90     | 170 × 75     | 256    | 4                    | 1              | 4        | 289.7    | 2:51      |
| DWI (EPI)          | 79      | 5000    | 90     | 230 × 50     | 160    | 4                    | 1              | 3        | 27.8     | 2:40      |
| DTI (EPI)          | 65      | 5000    | 90     | 230 × 50     | 128    | 4                    | 1              | 2        | 27.5     | 3:17      |

BW, bandwidth; DTI, diffusion tensor imaging; DWI, diffusion-weighted imaging; EPI, echo-planar imaging; FA, flip angle; FFE, fast field-echo; PDWI, proton density-weighted imaging; SE, spin-echo; SPAIR, spectral attenuated inversion recovery; SPIR, spectral pre-saturation inversion recovery; T$_1$WI, T$_1$-weighted imaging; T$_2^*$WI, T$_2^*$-weighted imaging; T$_1$WI, T$_1$-weighted imaging; TSE, turbo spin-echo.
Table 2 Signal-to-noise ratio of surface markers

|                | MR-SPOTS | Breath care | Baby oil | Wood marker |
|----------------|----------|-------------|----------|-------------|
| Survey         | 176      | 108         | 412      | 272         |
| \(T_1\)WI      | 277      | 301         | 287      | 159         |
| \(T_2\)WI      | 415      | 297         | 325      | 237         |
| PDWI           | 435      | 440         | 332      | 281         |
| \(T_2\)WI      | 78       | 45          | 43       | 103         |
| \(T_1\)WT SPIR | 299      | 29          | 34       | 140         |
| \(T_2\)WI SPAIR| 428      | 7           | 13       | 155         |
| PDWI SPAIR     | 437      | 150         | 250      | 282         |
| DWI (Isotropic)| 158      | 17          | 31       | 136         |
| DWI (Original) | 104      | 12          | 14       | 80          |
| DTI (Original) | 52       | 10          | 11       | 71          |

baby oil: Johnson & Johnson, New Brunswick, NJ, USA; Breath Care, Breath Care Oral Refreshing Capsule: Kobayashi Pharmaceutical Co., Ltd., Osaka, Japan; DTI, diffusion tensor imaging; DWI, diffusion-weighted imaging; MR-SPOTS, MR-SPOTS Packets: Beekley Medical, Bristol, CT, USA; PDWI, Proton density-weighted imaging; SPAIR, spectral attenuated inversion recovery; SPIR, spectral pre-saturation inversion recovery; \(T_1\)WI, \(T_2\)WI, \(T_2^*\)WI, \(T_1^*\)WI, \(T_2^*\)-weighted imaging; Wood marker, Chamaecyparis obtusa.

Table 3 shows the coefficient of variation for pairs of images. The coefficient of variation of the MR-SPOTS was larger than the coefficient of variation of the other sequences shown in the FA map; the wood marker had similar values in all sequences.

Results of microscopic observations are shown in Fig. 2. Wood tracheids with diameters of 10–30 μm were observed.

Discussion

Breath Care (420 ms [pre-study]) and baby oil (240 ms [pre-study]) had short \(T_1\)-relaxation times and high SNR for \(T_1\)WI. However, these \(T_1\)-relaxation times were close to fat (382 ms),\(^9\) and SNR decreased by fat suppression would be difficult to interpret without particularly careful studies. Itoh et al. reported that the SNR of Breath Care and baby oil decrease in fat suppression.\(^5\) The \(T_1\)-relaxation time of the wood marker (708 ms [pre-study]) and MR-SPOTS (651 ms [pre-study]) were longer than that of subcutaneous fat (382 ms), and were less affected by fat suppression.

Because MR-SPOTS are not anisotropic, they had lower FA values than those of the wood marker in the FA map. MR-SPOTS were found to be unsuitable as a marker in the FA map (Fig. 3). MR-SPOTS showed a low ADC value; however, the ADC values for the wood marker were higher than those for the MR-SPOTS in the ADC map. MR-SPOTS were evaluated to be unsuitable as a marker in the ADC map. Additionally, MR-SPOTS, Breath Care, and baby oil produced artifacts in the ADC map (Fig. 4), which required careful interpretation.
Different types of wood have variable FA values. FA values of various types of wood were investigated in the pre-study: *Trachycarpus*: FA value 0.1; water content 145%, *Liquidambar styraciflua*: FA value 0.3; water content 138%, *Camellia japonica*: FA value 0.5; water content 120%. The following formula was used to calculate the water content:

\[
\text{Water content} = \frac{\text{mass of water}}{\text{mass of wood infiltrated with water}} \times 100\%.
\]

The authors recommend *Chamaecyparis obtuse*: FA value 0.8; water content 187%, *Toxicodendron succedaneum*: FA value 0.7; water content 168%, and *Acer*: FA value 0.7; water content 180%. High FA values and high water content are important for wood markers because low water content causes low signal values.

The coefficient of variation of the wood marker was smaller than that of the other marker materials shown in the FA map, and was ≤0.0030 in all sequences. Values for the wood marker were reproducible compared to those of the other markers for all sequences.

GHAZIKHANLOU-SANI et al.10 used Medical Imaging Processing, Analysis, and Visualization (National Institutes of Health, Bethesda, MD, USA) software with \(T_1\) and \(T_2\). FA maps could be matched with one another, and the tumor water \(\times\) 100%. The authors recommend *Chamaecyparis obtuse*: FA value 0.8; water content 187%, *Toxicodendron succedaneum*: FA value 0.7; water content 168%, and *Acer*: FA value 0.7; water content 180%. High FA values and high water content are important for wood markers because low water content causes low signal values.

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|                   | MR-SPOTS | Breath care | Baby oil | Wood marker |
|-------------------|----------|-------------|----------|-------------|
| Survey            | 0.0017   | 0.0008      | 0.0014   | 0.0025      |
| \(T_1\)WI        | 0.0025   | 0.0020      | 0.0025   | 0.0003      |
| \(T_2\)WI        | 0.00160  | 0.0034      | 0.0039   | 0.0029      |
| \(T_2^*\)WI      | 0.0013   | 0.0008      | 0.0011   | 0.0017      |
| \(T_2\)WI SPIR   | 0.0005   | 0.0014      | 0.0039   | 0.0002      |
| \(T_2\)WI SPAIR  | 0.0006   | 0.0636      | 0.0393   | 0.0024      |
| \(T_2\)WI SPIRAIR| 0.0004   | 0.0023      | 0.0024   | 0.0005      |
| DWI (Isotropic)  | 0.0015   | 0.0148      | 0.0105   | 0.0013      |
| ADC map          | 0.0140   | N/A         | N/A      | 0.0005      |
| FA map           | 0.0263   | N/A         | N/A      | 0.0013      |

ADC, apparent diffusion coefficient; baby oil: Johnson & Johnson, New Brunswick, NJ, USA; Breath Care, Breath Care Oral Refreshing Capsule: Kobayashi Pharmaceutical Co., Ltd., Osaka, Japan; DWI, diffusion-weighted imaging; FA, fractional anisotropy; MR-SPOTS, MR-SPOTS Packets: Beekley Medical, Bristol, CT, USA; N/A, not available; PAIR, spectral attenuated inversion recovery; PDWI, proton density-weighted imaging; SPIR, spectral pre-saturation inversion recovery; ST\(_1\)WI, \(T_1\)-weighted imaging; \(T_2\)WI, \(T_2\)-weighted imaging; Wood marker, Chamaecyparis obtuse.
border, soft tissue, and bones could be identified on FA maps. However, the wood marker could be used to directly pinpoint the location of a lesion site on the FA map. Moreover, the proposed marker contributes to lesion localization in many sequences, including fat suppression. Therefore, radiologists may not need to compare the FA map with other images.

Our study had several limitations. Although cost was not determined, a wood marker would be generally inexpensive, and can be constructed by simply infiltrating a piece of wood with water and sealing it with vinyl tape. The cost of the wood marker may be lower than that of commercially available markers. To reduce the cost of essential elements in the clinic, capsule markers have been suggested as substitutes for expensive, commercially available markers.\textsuperscript{3,11,12} Rosahl et al.\textsuperscript{13} highlighted the excessive cost of commercially available markers and the superiority of shape.

Although the effect of marker shape was not assessed in the present study, a wood marker would be free of shape limitations. Any pressure from a flat marker would not be perceived by a patient. Markers made from wood would enable optimal shape variations, ranging from small to large. Conventional small-capsule markers may be overlooked in large FOV imaging.

Maintaining the quality of a marker was also not studied. However, preventing dryness of the wood marker could be achieved using a polypropylene case that is sealed with vinyl tape. Furthermore, dryness could be prevented by simply dipping the marker in water.

The comparison of markers was performed using phantoms alone. In future studies, the investigation could be extended by imaging human subjects using various markers. Additionally, such studies should include more subject data for various sequences along with comprehensive statistical analysis.

Other materials with known diffusion anisotropy were not considered. Asparagus, which has poor preservability, was excluded. Bundled Dyneema (TOYOBO CO., LTD, Osaka, Japan) was difficult to obtain. Glass plate capillaries were expensive. To make markers widely accessible, materials that were expensive and difficult to obtain were excluded.

**Conclusion**

The wood maker was evaluated as useful in DTI, and it enabled direct localization in the FA map. Furthermore, the wood marker yielded sufficient SNRs and coefficients of variation for various sequences. The design and development of a wood marker would be helpful to radiologists and contribute to obtaining useful findings.

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**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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