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MUSCULOSKELETAL

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Magic angle effect in MR imaging of ankle tendons: influence of foot positioning on prevalence and site in asymptomatic subjects and cadaveric tendons

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Abstract The influence of foot positioning on prevalence of the magic angle effect (MAE) in ankle tendons was investigated. In 30 asymptomatic volunteers and five cadaveric feet, MR imaging of the ankle was performed in the supine (neutral position of the foot) and prone (plantar-flexed foot) position. MAE was considered if increased T1-weighted signal at a certain site was seen in one position only. Histological correlation was obtained at 25 sites of the cadaveric posterior tibialis tendons (PTT). MAE occurred in 6/30 vs 1/30 (supine vs prone) anterior tibialis tendons (ATT), 30/30 vs 0/30 extensor hallucis longus and 27/30 vs 0/30 extensor digitorum longus tendons, 29/30 vs 0/30 PTTs, 30/30 vs 0/30 flexor digitorum and flexor hallucis longus tendons, 30/30 vs 1/30 peroneus brevis and 23/30 vs 1/30 peroneus longus tendons. At 12/25 cadaveric PTT sites where MAE was exclusively responsible for the increased signal, histology revealed normal tissue (11/12) or minimal degeneration (1/12). In conclusion, the supine body position with neutral position of the foot, a high prevalence (77–100%) of MAE in ankle tendons except for the ATT (20%) is seen. MAE is almost absent in the prone body position with plantar flexion of the foot.

Keywords MR imaging · Tendon · Ankle

Introduction

The magic angle effect (MAE) describes the orientation dependence of T2 relaxation times [1, 2]. The MAE occurs in tissues with well-ordered collagen fibers, such as tendons, ligaments or hyaline cartilage [3]. Depending on the orientation of the fibers to the main magnet field, B_0, an increase of the T2 relaxation time and respective signal occurs. The maximum signal increase is observed at the magic angle of 54.74° relative to the orientation of B_0 [3] and is evident on short echo-time MR (magnetic resonance) images with an echo time of less than 37 ms [4].

MR imaging (MRI) is well established in the evaluation of tendons of the ankle. Tendon degeneration is usually best seen on short echo-time images [5, 6]. On MR images tendon assessment is performed based on changes in morphology, signal intensities and associated findings in the synovial tendon sheath and bone marrow. Degeneration or tendinosis is characterized by caliber changes and increased signal intensity within the tendon on MR images

with short echo time. Increased signal abnormality on T2 weighted images is only noted when advanced intrasubstance changes are present. The morphologic criteria are difficult to assess at locations with physiologic enlargement of the tendon diameter; e.g., at the distal portion of the posterior tibialis tendon [7]. Thus, in such locations the assessment of signal changes gains importance for distinguishing MAE from tendinosis.

MRI of the ankle is usually performed with the foot in neutral position in supine patients. In several investigations [8–12] the MAE within ankle tendons in the standard position has been reported. Repeated scanning of the patient after repositioning has been recommended in case of equivocal findings [8–12]. In our clinical experience, we have learned that the MAE for the ankle tendon is almost absent in MR images of the foot in prone position.

The purpose of the study was to evaluate the influence of foot positioning on the prevalence and the site of the MAE for ankle tendons of volunteers and to assure by MRI histologic correlation in cadaver tendons that this signal increase is not caused by degeneration.

Materials and methods

The study was approved by the institutional review board. Informed consent was obtained from each volunteer. The cadaver feet were obtained and utilized according to the institutional guidelines and with informed consent of the donor prior to death or the appropriate family member and institutional approval.

Volunteers

A total of 30 ankles (16 right, 14 left) of 30 asymptomatic volunteers (22 women, eight men) were prospectively included in the study. The volunteers' age varied between 23 and 65 years (mean 42.8 years, female: age range 24–65 years, mean age 41.9 years; male: age range 23–62 years, mean age 45.1 years). Criteria for inclusion were: (1) no foot pain, (2) no trauma to the ankle or foot during the last two years, (3) never visited a physician for foot complaints, (4) no prior foot surgery and (5) no systemic inflammatory disease.

Cadaveric feet

Five human feet (two left, three right) of five non-embalmed cadavers were available. Prior to MRI, the cadaveric specimens were allowed to thaw for 24 h at room temperature. After imaging, the specimens were dissected by an orthopedic surgeon (P.B.S., six years experience in orthopedic surgery). The distal portion (6 cm from insertion to the navicular bone) of the posterior tibialis tendon (PTT) was removed and fixed in 10% neutral buffered formalin for histological evaluation.

MRI protocol

MRI was performed with a 1.5 T system (Symphony; Siemens Medical Solutions, Erlangen, Germany). Volunteers and cadaveric feet were examined in the supine body position with the ankle placed in neutral position in the extremity coil. T1-weighted spin-echo images were obtained in the sagittal plane (TR 450/TE 14, 3-mm section thickness, 22 cm field of view, matrix 512×256), coronal (TR 450/TE 14, 4-mm section thickness, 16 cm field of view, matrix 512×256) and in the transverse oblique plane, parallel to a line bisecting the angle between the long axis of the lower leg and the foot (TR 435/TE 14, 4-mm section thickness, 15 cm field of view, matrix 512×256). The transverse oblique plane was chosen to be as perpendicular as possible to the main orientation of the tendon around the ankle in order to minimize partial volume effects.

After evaluation the most comfortable position for maximal plantar flexion of the foot, the volunteers were examined in the prone body position with plantar flexion of the foot in the extremity coil. The cadaveric feet were positioned in "prone body position" with maximal plantar flexion and fixed with straps within the coil. The T1-weighted spine-echo images were obtained again in transverse oblique plane (parallel to a line bisecting the angle between the long axis of the lower leg and the foot) using the same parameters.

Volunteers study

Qualitative analysis of MR images

For the qualitative analysis of MR images, MR examinations were analyzed in consensus by two experienced musculoskeletal radiologists (two staff radiologist with 12 years (M.Z.) and 7 years (G.W.A.P.) experience in musculoskeletal radiology).

To ensure that they were blinded to the body position, the MR images were arranged and displayed on a PACS Workstation (Image Devices, Idstein, Germany) by a third radiologist (B.M., fellow with 2 years experience in musculoskeletal radiology) not involved in the qualitative analysis. Increased signal (none, partial thickness (part of the cross-section of the tendon), diffuse (whole cross-section of tendon)) within the ankle tendons was evaluated at the segments described in the following based on

anatomic landmarks. Signal increase was defined as increased signal compared with normal dark signal of tendon tissue.

Anterior group (see diagram to Table 2) Segments for the anterior tendon group [anterior tibialis tendon (ATT), extensor hallucis longus tendon (EHL) and extensor digitorum longus tendon (EDL)] were: (1) the inferior tip of the medial malleolus to proximal navicular border, (2) above the navicular bone, (3) above the medial cuneiform and (4) at the base of the first metatarsal. For the EDL each tendon was evaluated separately (Dig. II–V).

Medial group (see diagram to Table 3) Segments for the medial tendon group [posterior tibialis tendon (PTT), flexor digitorum longus tendon (FDL) and flexor hallucis longus tendon (FHL)] were: (1) retromalleolar, (2) the inferior tip of the medial malleolus to posterior border of sustentaculum, (3) the posterior border to the center of the sustentaculum, (4) the center to the anterior border of the sustentaculum, (5) the anterior border of the sustentaculum to the navicular insertion of PTT and (6) distal of the navicular insertion of the PTT.

Lateral group (see diagram to Table 4) Segments for the lateral tendon group [peroneus brevis (PB) and longus (PL) tendon] were defined as: (1) supramalleolar, (2) retromalleolar, (3) the inferior tip of the lateral malleolus to the trochlear process and (4) the trochlear process to the base of the fifth metatarsal bone. In addition, for the PL, the segments (5) peroneal trochlea to the lateral edge of cuboid and (6) plantar portion of the PL, were analyzed.

Angle measurements

In the supine body position with the ankle placed in neutral position the angle of the tendons to the main magnetic field B_0 was measured at the site of increased signal within the tendons. Measurements were performed on the sagittal T1-weighted images by a by a fellow in musculoskeletal radiology (B.M.., 2 years experience in musculoskeletal radiology) using a PACS Workstation (Image Devices, Idstein, Germany). Measurements were obtained to the nearest one-tenth of a degree and then rounded to the nearest degree. For the EHL, EDL, PTT, FDL, FHL, PB and lateral portion of the PL tendon a straight course within the sagittal plane was assumed. The measured angle in this plane was considered to be the effective angle to the main magnetic field B_0. Due to the oblique course of the distal portion of the ATT and the plantar portion of the PL tendon, two angles were measured in sagittal (α) and coronal (β)

Table 1 Increased signal, MAE within the ankle tendon in supine (neutral position of the foot) and prone (plantar flexion of the foot) body position and measurements of angle to B_0 at site of increased signal (*ATT* anterior tibialis tendon, *EHL* extensor hallucis longus tendon, *EDL* extensor digitorum longus tendon, *PTT* posterior tibialis tendons, *FDL* flexor digitorum, *FHL* flexor hallucis longus tendon, *PB* peroneus brevis tendon, *PL* peroneus longus tendon)

Body position	Anterior group			Medial group			Lateral group	
	ATT	EHL	EDL	PTT	FDL	FHL	PB	PL
Supine								
Increased signal								
None	24 (80%)	0 (0%)	3 (10%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Partial	6 (20%)	1 (3%)	2 (7%)	4 (13%)	2 (7%)	0 (0%)	4 (13%)	2 (7%)
Diffuse	0 (0%)	29 (97%)	25 (83%)	26 (87%)	28 (93%)	30 (100%)	23 (77%)	28 (93%)
Prone								
Increased signal								
None	29 (97%)	30 (100%)	30 (100%)	29 (97%)	30 (100%)	30 (100%)	27 (90%)	4 (13%)
Partial	1 (3%)	0 (0%)	0 (0%)	1 (3%)	0 (0%)	0 (0%)	3 (10%)	4 (13%)
Diffuse	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	22 (74%)
Identified MAE within tendon								
Supine	6 (20%)	30 (100%)	27 (90%)	29 (97%)	30 (100%)	30 (100%)	30 (100%)	23 (77%)
Prone	1 (3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (3%)[a]	2 (6%)
P value	0.125	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mean angle[b] to B_0 in supine position(°)	60.1 (56–65)	55.0 (49–68)	54.9 (48–65)	55.2 (49–61)	55.3 (50–61)	58.3 (53–62)	53.4 (46–61)	55.6 (50–60)

[a]Increased signal seen in prone position was in a different segment than in supine position
[b]Angle of tendon site with increased signal to B_0

planes. The effective angle relative to B_0 was calculated with the following formula:

$$\cos(\text{angle eff}) = \frac{1}{\sqrt{\left(\frac{1}{tan\alpha}\right)^2 + \left(\frac{1}{tan\beta}\right)^2 + 1}}$$

Cadaver study with MRI histologic correlation

Analysis of MR images

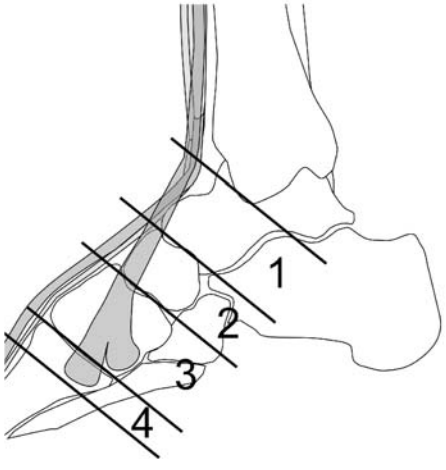
The MR examinations were analyzed in consensus by the same two experienced musculoskeletal radiologists blinded to the body position. To ensure that they were blinded to the body position, the MR images were arranged and displayed by a third radiologist (B.M., fellow with 2 years experience in musculoskeletal radiology) not involved in the analysis. Increased signal [none, partial thickness (part of the cross-section of the tendon), diffuse (whole cross-section of tendon)] within the PTT were evaluated at the navicular insertion and at 1, 2, 3 and 4 cm from this insertion.

Histologic analysis of the PTT specimen

The excised specimens were embedded in paraffin wax. Histologic sections with a thickness of 4 μm that were obtained at an exact right angle to the long axis of the tendon to match closely the orientation of the MR images. Sections were obtained at the navicular insertion and at 1, 2, 3 and 4 cm from the navicular insertion. The sections were mounted on slides, stained with hematoxylin-eosin as well as periodic acid schiff (PAS) and examined with a light microscope.

The specimens were evaluated by a board certified pathologist with 6 years of experience (B.B.) in musculoskeletal pathology. Possible histologic diagnosis were: (1) mucoid degeneration, (2) pseudocystic changes, (3) neovascularisation, (4) fibrocartilage, (5) chondroid and (6) osseous sesamoids. The extent of degeneration was graded 0–3 (0=none, 1=few, 2=moderate, 3=severe). In case of the existence of fibrocartilage the location within the tendon diameter was noted [medial, central, lateral (close to bone)].

Table 2 Anterior tendon group: location and prevalence of increased signal on T1-weighted images (iS) and magic angle effect (MAE) depending on positioning [supine (neutral position of the foot) vs prone (plantar flexion of the foot) position] (*ATT* anterior tibialis tendon, *EHL* extensor hallucis longus tendon, *EDL* extensor digitorum longus tendon)



n=30	Location of increased signal and identified MAE											
Location/Segments	ATT				EHL				EDL			
	Supine		Prone		Supine		Prone		Supine		Prone	
	iS	MAE	iS	MAE	iS	MAE	iS	MAE	iS	MAE	iS	MAE
1 Inferior tip of medial malleolus to proximal navicular border	2	2	0	0	25	25	0	0	27	27	0	0
2 above navicular bone	4	4	0	0	30	30	0	0	26	26	0	0
3 above medial cuneiform	5	4	1	0	30	30	0	0	25	25	0	0
4 at base of first metatarsal	2	2	1	1	30	30	0	0	25	25	0	0
EDL portions with MAE												
Dig. II									27			
Dig. III									22			
Dig. IV									5			
Dig. V									0			

Statistical analysis

For the volunteers study MAE at a certain site of the tendon was considered positive if an increased signal at one particular site was only observed in one body position and if this signal was completely normal (hypointense) in the other position. Considering that MAE could be present in different tendon segments it was possible that MAE was present in both positions in the same tendon. The prevalences of identified MAE depending on positioning were compared with the McNemar Test.

A *P* value of less than 0.05 was considered to be statistically significant. For statistical analysis SPSS for Windows (version 10.0.1, 1999) was used.

Results

Volunteers study

Detailed results with prevalence and site of increased T1-weighted signal and the MAE are listed in Tables 1, 2, 3, 4.

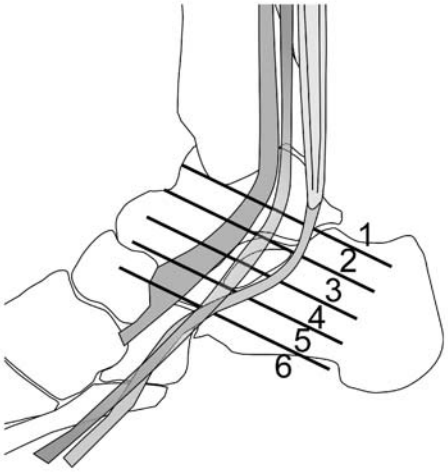
Qualitative analysis of MR images

Anterior group (Table 2) In the supine position MAE was observed in six (20%) ATTs predominantly above the navicular [4 (13%)] and medial cuneiform [4 (13%)]. In the prone position, MAE was seen only in one (3%) ATT at the base of the first metatarsal.

In the supine position, all EHL tendons and 28 (90%) EDL tendons showed a MAE (Fig. 1). The most common involved portions of the EDL were the second (27/28) and the third (22/28) tendon of the EDL. In the prone position no MAE was seen within the EHL and the EDL tendons.

Medial group (Table 3) In the supine position, MAE was identified in 29 (97%) PTT tendons (Fig. 1b). The MAE was predominantly located in the distal portion of the PTT between the posterior border of the sustentaculum tali and the navicular insertion of the tendon. In the prone position, no PTT revealed a MAE. In the supine position, all 30 FDL and all 30 FHL showed a MAE. MAEs of the FHL were predominantly found between the inferior tip of the medial malleolus and the anterior border of the sustentaculum (Fig. 1a). The MAE within the FDL tendons was

Table 3 Medial tendon group: location and prevalence of increased signal on T1-weighted images (iS) and magic angle effect (MAE) depending on positioning [supine (neutral position of the foot) vs prone (plantar flexion of the foot) position] (*PTT* posterior tibialis tendons, *FDL* flexor digitorum, *FHL* flexor hallucis longus tendon)

		n=30	Location of increased signal and identified MAE											
Location/Segments			PTT				FDL				FHL			
			Supine		Prone		Supine		Prone		Supine		Prone	
			iS	MAE	iS	MAE	iS	MAE	IS	MAE	iS	MAE	iS	MAE
	1	retromalleolar	2	2	0	0	0	0	0	0	0	0	0	0
	2	Inferior tip of medial malleolus to posterior border of sustentaculum	11	11	0	0	0	0	0	0	21	21	0	0
	3	posterior border to center of sustentaculum	20	20	0	0	5	5	0	0	24	24	0	0
	4	center to anterior border of sustentaculum	29	29	0	0	14	14	0	0	17	17	0	0
	5	Anterior border of sustentaculum to navicular insertion of PTT	29	28	1	0	26	26	0	0	8	8	0	0
	6	distal of navicular insertion of PTT	_		_		29	29	0	0	3	0	0	0

found more distally compared with the FHL, starting at the posterior border of the sustentaculum (Fig. 1b). In the prone position, no FDL and FHL tendons revealed a MAE.

Lateral group (Table 4) In the supine position, all 30 PB tendons showed a MAE. The MAE was most often seen in the distal segments from the inferior tip of lateral malleolus to the base of the fifth metatarsal bone (Fig. 1). In the prone position, in one (3%) PB tendon MAE could be identified in the retromalleolar segment. That means increased signal was seen in the retromalleolar segment in the prone position but not in the supine position. In the supine position, a MAE was identified in 23 (77%) PL, predominantly within the segment from the peroneal trochlea to the lateral edge of cuboid (Fig. 1b). In the prone position, in two (6%) PL tendons a MAE could be identified. However, within the plantar segment with an oblique course of the PL tendon a high prevalence of increased signal was seen in both the supine [30 (100%)] and the prone [26 (87%)] body position. Thus, only in four (13%) PL tendons could a MAE be identified in this segment in the supine body position.

Angle measurements (Table 2) In the supine body position, the mean angle of the tendon sites with increased signal to the main magnetic field, B_0, was 60.1° for the ATT, 55.0° for the EHL, 54.9° for the EDL, 55.2° for the PTT, 55.3° for the FDL, 58.3° for the FHL, 53.4° for the PB, and 55.6° for the lateral portion of the PL. At the plantar portion of the PL the mean angle was 76.2°.

Cadaver study with MRI histologic correlation

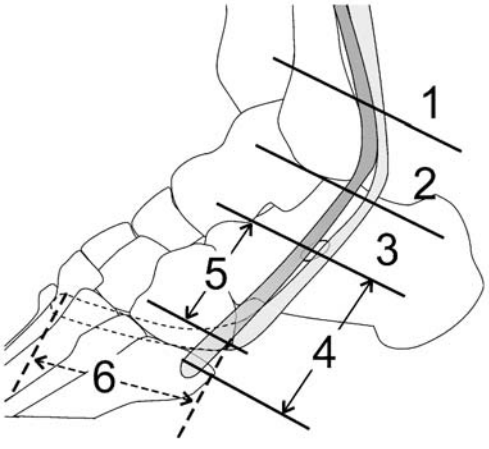
Results are summarized in Table 5

In the supine position, increased signal was observed in 21/25 evaluated PTT sites. At 4/25 sites no increased signal was visible, either in the supine or in the prone body position.

After repositioning to the prone position, the increased signal disappeared completely or partially at 19/21 PTT sites. At 12/19 PTT sites the signal increase disappeared completely. In 11 of these 12 evaluated sites, histology revealed normal tendon tissue (Fig. 2a) and, at one location, minimal degeneration. At 7/19 PTT sites the signal increase disappeared only partially [location of persisting signal: lateral (close to bone) 5, central 2]. The histological analysis of these tendon sites showed normal tendon tissue in 3/7 (Fig. 2b) and tendon degeneration in 4/7 locations (2/7 few, 1/7 moderate, 1/7 severe) (Fig. 2c). At all seven sites, fibrocartilaginous tissue was visible at

Table 4 Lateral tendon group: Location and prevalence of increased signal on T1-weighted images (iS) and magic angle effect (MAE) depending on positioning [supine (neutral position of the foot) vs prone (plantar flexion of the foot) position] (*PB* peroneus brevis tendon, *PL* peroneus longus tendon)

	n=30	Location of increased signal and identified MAE							
Location/Segments		**PB**				**PL**			
		Supine		Prone		Supine		Prone	
		iS	MAE	IS	MAE	iS	MAE	iS	MAE
1	supramalleolar	0	0	1	1	0	0	0	0
2	retromalleolar	17	14	3	0	3	3	1	1
3	inferior tip of lateral malleolus to the trochlear process	25	22	3	0	4	4	1	1
4	trochlear process ñ Base of 5th metatarsal	27	26	1	0	_		_	
5	trochlear process to the lateral edge of cuboid	_		_		26	23	3	0
6	plantar portion of PL	_		_		30	4	26	0



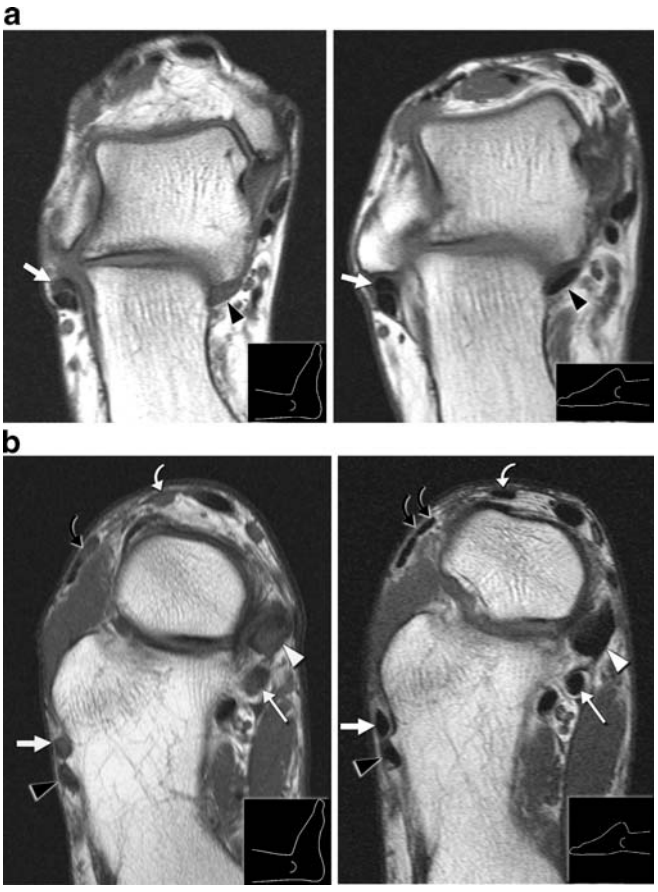


Fig. 1a,b Magic angle effect in MRI of ankle tendons in asymptomatic subjects. Transverse oblique T1-weighted images (435/14) in supine body position with neutral position of the foot (*left*) and in prone body position with plantar flexion of the foot (*right*). **a** Imaging plane at the inferior tip of medial malleolus (51-year-old asymptomatic woman). In supine body position (*left*), the PB tendon (*white arrow*) and the FHL tendon (*black arrowhead*) show diffusely increased signal due to MAE. After repositioning with plantar flexion of the foot (*right*) a normal dark signal is seen within the PB and FHL tendons. At this level no MAE is seen within the ATT, PTT, FDL and PL tendons. **b** Imaging plane just anterior to the sustentaculum tali at the level of the trochlear process of the calcaneus (37-year-old asymptomatic man). In the supine body position with neutral position of the foot (*left*), MAE with diffusely increased signal is visible within the PTT (*white arrowhead*), FDL (*smallwhite arrow*), PB (*white arrow*), PL (*black arrowhead*), EHL (*curved white arrow*) and EDL tendon (second and third tendon) (*curved black arrow*). In this position only the ATT and the FHL tendon have no MAE. In the prone body position with plantar flexion of the foot (*right*), all ankle tendons show a normal dark signal with no MAE

the lateral (close to bone) portion of the tendon. In addition, in two of the three tendons with normal histology a cartilaginous sesamoid was seen which corresponds to the increased signal on MRI (Fig. 2b).

At 2/21 sites, increased signal seen in the supine position persisted after repositioning to the prone position. Histology revealed severe degeneration at one site and little degeneration at the others.

Discussion

The dipole interaction between two spinning nuclei, which leads to a reduced signal intensity, disappears at the "magic" angle of 54.74° to the main magnetic field B_0 and the T2 decay is decelerated [3]. Tendons, retinacula, ligaments and cartilage have a highly ordered structure with parallel orientation of collagen fibers (structural anisotropy). Water molecules binding to the collagen triple helix are ordered in-line with restricted mobility. If the collagen fibers are oriented 55° to B_0, the spin interaction of the water molecules disappears and the T2 time is increased.

Although tendons around the ankle are predisposed for the MAE due to the curved course, in most institutions MRI of the ankle is performed in the supine body position with the ankle in neutral position. Our data demonstrate that in this position increased signal occurs with a high prevalence (77–100%) in all ankle tendons with exception of the ATT. The measured angles at the location of signal increase (mean 53.4°–60.1°) and the results of the cadaver study with MR histologic correlation underline that this increase of signal is due to MAE. This is in contrast to the prone body position with the ankle in plantar flexion, where the MAE was rarely identified. The only tendon portion with a persisting increased signal in both the supine and prone positions was the plantar portion of the PL tendon where it transverses the sole of the foot. The measured angle at this location (mean 76.2, range 63°–88°) suggests that MAE is not responsible for the signal increase. It is most likely that is caused by a partial volume effect using the transverse oblique plane for the qualitative evaluation of the signal intensities.

In tendon changes leading to increased signal on long TE sequences as T2-weighted images the MAE in short TE sequences will not cause any diagnostic dilemma. However, tendons with mild tendinosis commonly have a normal appearance on T2-weighted images. Signal abnormalities on T2-weighted images are only detectable in advanced degeneration [13]. In case of normal signal on T2-weighted images the MAE may be difficult to differentiate from signal increase of the tendon caused by early tendon degeneration seen on short TE images [5, 6].

The typical location for PTT disorders are at the level of the medial malleolus and more distally in the 2–3 cm proximal to the insertion site at the navicular bone [7, 14, 15]. In the supine position, MAE occurred in 7% of the PTT in the retromalleolar segment and in 93% (28/30) and 97% (29/30) in the two distal segments of the tendons. In the prone position, no MAE was seen. In this distal portion of the PTT enlargement and intratendinous increased signal are evident on MR images in asymptomatic subjects [7, 15, 16], both are diagnostic criteria for a tendinosis or a partial tear [13]. It was assumed that this increased signal in the distal PTT is related to volume averaging with the superomedial calcaneonavicular and the tibiospring liga-

Table 5 Results of cadaveric study. Behavior of increased signal on T1-weighted images by repositioning from the supine to prone body position. Correlation of MR and histological findings at five sites (0, 1, 2, 3, 4 cm from navicular insertion) within the five cadaveric PTTs (n=25)

Histology	Increased signal in supine position 21/25			No increased signal in supine position 4/25
	MAE responsible (completely or partially) for increased signal 19/25		MAE not responsible for increased signal 2/25	
	Increased signal only due to MAE *12/25*	Increased signal partially due to MAE *7/25*		
Normal	*12*	*3*	*0*	*3*
Degeneration	*1*	*4*	*2*	*1*
Degree of degeneration				
Few	1	2	1	1
Moderate		1	0	0
Severe		1	1	0
Histologic findings				
Myxoid degeneration	1	4	2	1
Pseudocystic changes	0	2	1	0
Neovascularisation	1	3	1	1
Lateral fibrocartilage	6	7	1	1
Sesamoid				
Chondroid	0	2	0	0
Csseous	1	1	1	0

ment [17]. Recently, Default et al. [16] investigated signal variation in the normal distal PTT in asymptomatic subjects and cadaveric ankles: 12 of the 33 asymptomatic subjects (36%) had an increased intratendinous signal distally on proton-density images (TE of 19 ms). One hundred percent of these distal increased signals were laterally off-centered. In seven of ten PTTs, an eccentric intratendinous fibrocartilaginous sesamoid were seen in their study, and in one PTT, a sesamoid bone was seen. The authors therefore concluded that the lateral off-centered increased intratendinous signal seen in the asymptomatic subjects was caused by intratendinous fibrocartilage. Our data of the cadaveric study with histological correlation demonstrates that increased T1-weighted signal within the distal portion of the PTT in the standard supine body position is usually caused by the MAE. In 90% (19/21 sites), the increased signal within the evaluated portion of the distal PTT was either exclusively (12/21) or partially (7/21) due to MAE. Persisting increased signal after repositioning (9/21) was either due to degenerative changes (6/9) or fibrocartilage/chondroid sesamoid (3/9). It was discussed that this fibrocartilage tissue may be an indicator for altered biomechanical stress [18].

In our study, we visually evaluated the signal intensity reflecting the daily routine reading MR images. Thus, without quantitative measurement of the signal intensities, we cannot exclude any additional factors, like receiver gain and coil loading, that may differ between the two acquisitions and influence the signal intensities. Hence, the measured angles at sites of increased signal were around 55° (mean values between 53.4° and 60.1°) underlining that the signal increase is mainly caused by the MAE.

Alternatively to the prone body position with plantarflexed foot, the foot could be plantar flexed in the supine body position to avoid MAE. In our experience, this position is less comfortable and results in more motion artifacts than the well-tolerated prone body position.

In conclusion, in the standard supine body position with neutral position of the foot, a high prevalence (77–100%) of MAE in ankle tendons—except for the ATT tendon (20%)—is seen. MAE in the ankle tendons is almost absent in the prone body position with plantar flexion of the foot. This position may be considered for assessment of the ankle tendons.

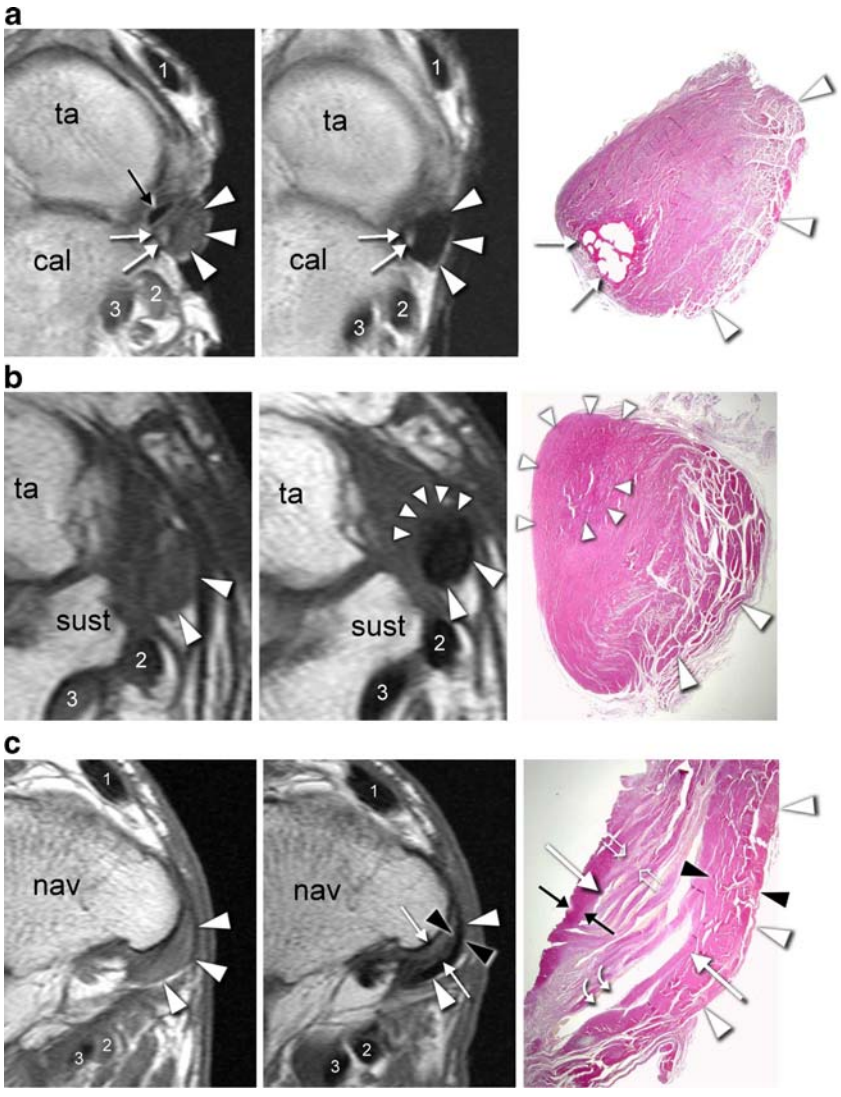


Fig. 2a–c Cadaver study: correlation of MR and histological findings of the posterior tibialis tendon (PTT). Transverse oblique T1-weighted images (435/14) in the supine body position with neutral position of the foot (*left*) and in prone body position with plantar flexion of the foot (*middle*) and the corresponding histology specimen (elastica-van Gieson staining, original size magnified 6×). *ta* talus, *cal* calcaneus, *sust* sustentaculum tali. **a** Normal PTT site with a osseous sesamoid (*white arrows*) 3 cm from navicular insertion. In the supine body position (*left*), a diffuse increase signal of the PTT (*white arrowheads*), FDL (*2*) and FHL tendon (*3*) due to MAE is visible. The dark signal lateral to the PTT (*black arrow*) is caused be a small air bubble in the cadaveric foot. After repositioning to prone body position with plantar flexion of the foot (middle) a normal dark signal is seen within the PTT, FDL and FHL tendon. The corresponding histology specimen (*right*) revealed a normal histology with a osseous sesamoid. Note no MAE is visible within the ATT (*1*). **b** Normal PTT site with a fibrocartilaginous sesamoid 2 cm from navicular insertion. The diffuse increased signal within the PTT (*large white arrowheads*) in supine body position with neutral position of the foot (*left*) is mainly caused by the MAE: after repositioning to prone body position with plantar flexion of the foot (*middle*) the increased signal within the PTT persisted in a small portion superolateral (*small white arrowheads*). At this location, a fibrocartilaginous sesamoid (*small white arrowheads*) is seen in the histology specimen (*right*). No degeneration of the PTT is visible. Note the MAE within the FDL (*2*) and FHL (*3*) tendon. **c** Severely degenerated PTT site at navicular insertion. In supine position (*left*) the PTT (*large white arrowheads*) shows a diffusely increased signal which was only partially due to MAE: after repositioning to prone body position (*middle*) the medial portion shows a normal dark signal (*black arrowheads*) with normal histology (*right*). In contrast, the lateral portion close to the navicular bone shows a persisting increased signal (*white arrows*) after repositioning. At this location (*white arrows*) the histology specimen (*right*) revealed severe myxoid degeneration (*open white arrows*) and pseudocystic changes (*white curved arrows*). At the site of insertion fibrocartilage (*black arrows*) is visible, which is a normal finding. Note the MAE within the FDL (*2*) (diffuse) and the FHL (*3*) (partially) tendon. No MAE is visible within the ATT (*1*)

References

1. Fullerton GD, Cameron IL, Ord VA (1985) Orientation of tendons in the magnetic field and its effect on T2 relaxation times. Radiology 155 (2):433–435
2. Berendsen H (1962) Nuclear magnetic resonance study of collagen hydration. J Chem Phys 36:3297–3305
3. Erickson SJ, Prost RW, Timins ME (1993) The "magic angle" effect: background physics and clinical relevance. Radiology 188(1):23–25
4. Peh WC, Chan JH (1998) The magic angle phenomenon in tendons: effect of varying the MR echo time. Br J Radiol 71(841):31–36
5. Timins ME, Erickson SJ, Estkowski LD, Carrera GF, Komorowski RA (1995) Increased signal in the normal supraspinatus tendon on MR imaging: diagnostic pitfall caused by the magic-angle effect. AJR 165(1):109–114
6. Kjellin I, Ho CP, Cervilla V, Haghighi P, Kerr R, Vangness CT et al (1991) Alterations in the supraspinatus tendon at MR imaging: correlation with histopathologic findings in cadavers. Radiology 181(3):837–841
7. Schweitzer ME, Caccese R, Karasick D, Wapner KL, Mitchell DG (1993) Posterior tibial tendon tears: utility of secondary signs for MR imaging diagnosis. Radiology 188(3):655–659
8. Klein MA (1993) Reformatted three-dimensional Fourier transform gradient-recalled echo MR imaging of the ankle: spectrum of normal and abnormal findings. AJR 161(4):831–836
9. Noto AM, Cheung Y, Rosenberg ZS, Norman A, Leeds NE (1989) MR imaging of the ankle: normal variants. Radiology 170(1 Pt 1):121–124
10. Cheung Y, Rosenberg ZS, Magee T, Chinitz L (1992) Normal anatomy and pathologic conditions of ankle tendons: current imaging techniques. Radiographics 12(3):429–444
11. Link SC, Erickson SJ, Timins ME (1993) MR imaging of the ankle and foot: normal structures and anatomic variants that may simulate disease. AJR 161(3):607–612
12. Erickson SJ, Cox IH, Hyde JS, Carrera GF, Strandt JA, Estkowski LD (1991) Effect of tendon orientation on MR imaging signal intensity: a manifestation of the "magic angle" phenomenon. Radiology 181(2):389–392
13. Rosenberg ZS, Beltran J, Bencardino JT (2000) From the RSNA Refresher Courses. Radiological Society of North America. MR imaging of the ankle and foot. Radiographics 20 Spec NoS153–179
14. Khoury NJ, el-Khoury GY, Saltzman CL, Brandser EA (1996) MR imaging of posterior tibial tendon dysfunction. AJR 167(3):675–682
15. Rosenberg ZS, Cheung Y, Jahss MH, Noto AM, Norman A, Leeds NE (1988) Rupture of posterior tibial tendon: CT and MR imaging with surgical correlation. Radiology 169(1):229–235
16. Delfaut EM, Demondion X, Bieganski A, Cotten H, Mestdagh H, Cotten A (2003) The fibrocartilaginous sesamoid: a cause of size and signal variation in the normal distal posterior tibial tendon. Eur Radiol 13(12):2642–2649
17. Rule J, Yao L, Seeger LL (1993) Spring ligament of the ankle: normal MR anatomy. AJR 161(6):1241–1244
18. Kiter E (2005) The fibrocartilage sesamoid. Eur Radiol 15(2):397–398; author reply 399