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SCIENTIFIC ARTICLE

Correlation of morphologic and pathologic features of the various tendon groups around the ankle: MR imaging investigation

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Abstract

Objective To determine if a statistical association exists between abnormalities in one ankle tendon group (i.e., peroneal, medial flexor, or Achilles) and those in another.

Materials and methods A retrospective analysis of 1.5-T and 3-T MR ankle examinations in 100 patients conducted between November 1, 2011 and April 1, 2012 was performed. The cross-sectional areas and diameters of the ankle tendons—Achilles (ACH), peroneus brevis (PB) and longus (PL), tibialis posterior (TP), flexor digitorum longus (FDL), and flexor hallucis longus (FHL)—were measured, and the results were correlated to determine any association with the presence of qualitative abnormalities (tenosynovitis, tendinosis, and tendon tearing).

Results Subjects with larger diameters of the ACH tendon also revealed larger PL, TP, FDL, and FHL tendon

diameters and sectional areas. Furthermore, subjects with larger PL tendons generally revealed larger flexor tendons and the same was also true when medial compartment tendons were individually assessed and measurements compared among the three of them. There was a statistically significant association with regard to the presence of tendon abnormalities (tendinosis, tenosynovitis, and tearing) in both the peroneal and medial flexor tendons. The presence of an abnormality in the ACH tendon correlated strongly with increasing diameters and areas of all the other ankle tendons except for the PB tendon.

Conclusions There is an association between quantitative and qualitative abnormalities of one group of tendons when compared with the others with respect to the ACH, medial flexor, and peroneal tendons of the ankle, which is perhaps explained by a retinacular and fascial complex that anatomically connects the three groups.

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Introduction

Gross cadaveric studies have confirmed a complex interconnected system of retaining fascia and retinacula in the distal aspect of the leg, just above and at the level of the ankle, that create distinct tendon compartments [1, 2]. Furthermore, recent evidence has shown that these and other retinacula also play a functional role, as they are not simply static structures for joint stabilization, like ligaments, but rather provide local spatial proprioception during movements of the foot and ankle [3]. One well-described example of this anatomic interconnected system is the continuity of the superior peroneal retinaculum and the flexor retinaculum of the ankle with the superficial and deep layers of the crural

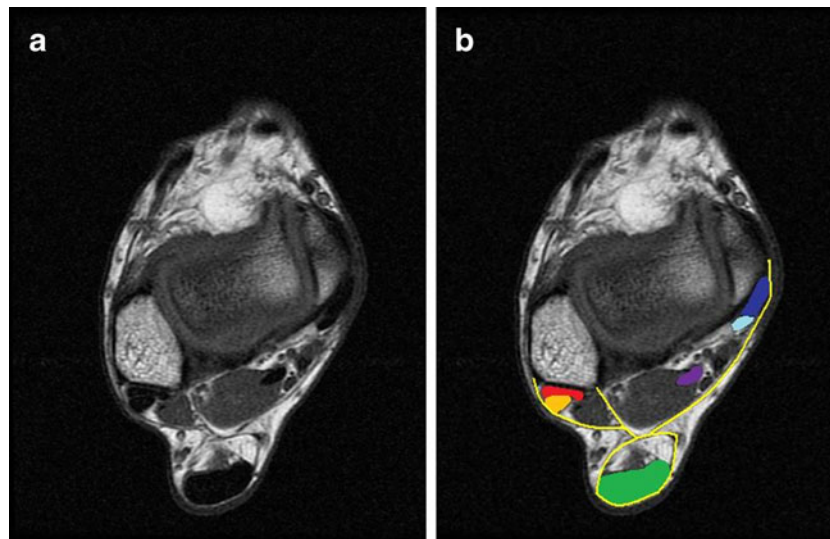


Fig. 1 Axial T1-weighted MR image depicting the retinacula and the tendons at the ankle. The tendons are painted: the Achilles is *green*, the peroneus longus is *red*, the peroneus brevis is *orange*, the tibialis posterior is *dark blue*, the flexor digitorum longus is *light blue* and the flexor hallucis longus is *purple*. The *yellow line* corresponds to the

retinacula. It is subdivided in the superior peroneal retinaculum attaching laterally to the lateral malleolus and medially in continuity with the superficial and deep aponeuroses of the posterior compartment of the lower portion of the leg. The segment of retinacula around the flexor tendons is called the flexor retinaculum

fascia, together forming a basket-shaped structure around the Achilles (ACH) tendon in the region of the pre-Achilles fat pad (Fig. 1).

Owing to the presence of this system, myofascial pathology, even if located far from the ankle, may produce traction on the

retinacula at the level of the ankle and eventually predisposing to tendon, ligament, or even articular abnormalities [4].

A link between ACH tendon disorders and abnormalities of the surrounding retinacula has been emphasized, we

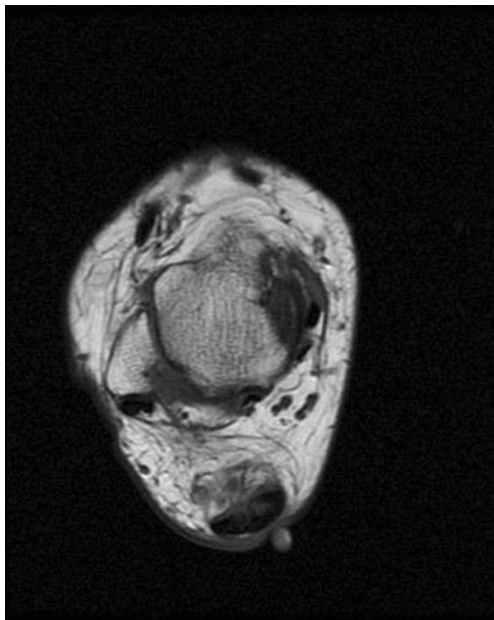


Fig. 2 Axial T1-weighted MR image 15 mm above the fibular tip, where the peroneal tendons were measured. Notice the association between partial Achilles tendon rupture and flexor hallucis longus tenosynovitis

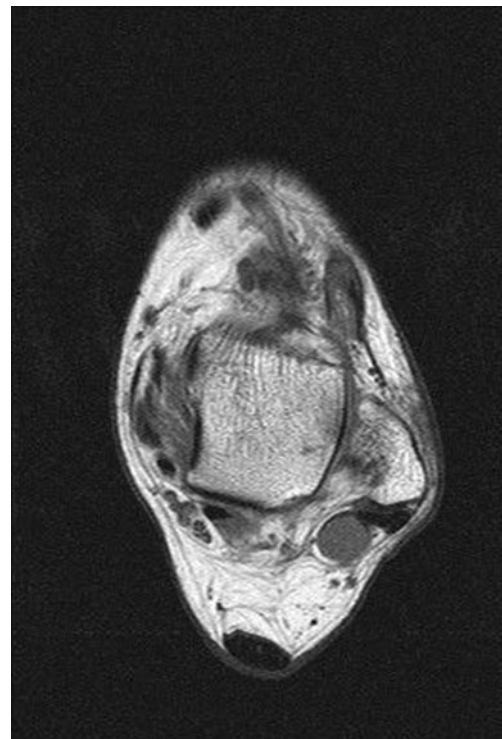


Fig. 3 Axial T1-weighted MR image 6 mm below the level of the talar dome, where the flexor tendons were measured

Table 1 Mean, 10th, 50th, and 90th percentiles, range and standard deviation for diameters and area of ankle tendons (cm)

Tendons	Diameter/area	Mean	10th percentile	50th percentile (median)	90th percentile	Range	Standard deviation
Achilles	Transverse	1.421	1.129	1.365	1.764	0.930–2.320	0.282
	Anteroposterior	0.726	0.549	0.670	1.041	0.450–1.480	0.214
Peroneus longus	Transverse	0.672	0.500	0.670	0.860	0.280–1.010	0.139
	Anteroposterior	0.412	0.259	0.410	0.561	0.170–0.790	0.115
	Area	0.216	0.124	0.214	0.306	0.069–0.446	0.072
Peroneus brevis	Transverse	0.645	0.339	0.605	0.970	0.170–1.380	0.246
	Anteroposterior	0.298	0.139	0.250	0.500	0.080–1.060	0.171
	Area	0.143	0.063	0.118	0.281	0.034–0.699	0.098
Tibialis posterior	Transverse	0.485	0.330	0.480	0.632	0.210–0.890	0.130
	Anteroposterior	1.042	0.799	1.040	1.300	0.440–1.590	0.208
	Area	0.397	0.229	0.371	0.579	0.137–0.874	0.134
Flexor digitorum longus	Transverse	0.490	0.329	0.470	0.662	0.190–0.930	0.133
	Anteroposterior	0.398	0.250	0.380	0.551	0.190–0.800	0.122
	Area	0.152	0.088	0.140	0.221	0.048–0.436	0.060
Flexor halluc longus	Transverse	0.541	0.400	0.510	0.710	0.990–0.250	0.130
	Anteroposterior	0.381	0.259	0.380	0.482	0.620–0.190	0.090
	Area	0.165	0.092	0.152	0.237	0.043–0.463	0.065

believe, only twice in the literature [5, 6]. Although abnormalities of the ACH, peroneal, and medial flexor tendons of the ankle have been widely studied, these tendon groups have always been regarded as independent structures, and a possible anatomical and functional

association of pathology in these groups has largely been ignored [7–13].

Anecdotal evidence in our clinical practice appears to show an association of ACH tendon abnormalities with similar abnormalities of other ankle tendons, particularly

Table 2 Relationship between the dimensions of the Achilles tendon and the other ankle tendons

Tendons	Diameter/area	Achilles tendon transverse diameter		Achilles tendon anteroposterior diameter	
		<i>p</i> value ^a	<i>r</i> value ^b	<i>p</i> value ^a	<i>r</i> value ^b
Peroneus longus	Transverse	<0.001	0.345	0.035	0.212
	Anteroposterior	0.073	0.18	0.027	0.222
	Area	<0.001	0.393	<0.001	0.368
Peroneus brevis	Transverse	0.061	0.188	0.260	0.114
	Anteroposterior	0.367	−0.910	0.937	−0.008
	Area	0.905	−0.012	0.677	0.042
Tibialis posterior	Transverse	0.457	0.075	0.100	0.165
	Anteroposterior	0.007	0.266	0.027	0.221
	Area	0.014	0.244	0.004	0.287
Flexor digitorum longus	Transverse	0.001	0.335	0.001	0.326
	Anteroposterior	0.518	0.065	0.171	0.138
	Area	0.003	0.295	<0.001	0.355
Flexor halluc longus	Transverse	<0.001	0.400	0.018	0.237
	Anteroposterior	0.005	0.276	<0.001	0.368
	Area	<0.001	0.415	<0.001	0.347

^a Calculated with ANOVA test^b Calculated with Pearson correlation test

Table 3 Relationship between the dimensions of the peroneal tendons and the medial flexor tendons

Tendons	Diameter/area	Peroneus Longus tendon			Peroneus Brevis tendon								
		Transverse		Anteroposterior	Transverse		Anteroposterior						
		p value ^a	r value ^b	p value ^a	p value ^a	r value ^b	p value ^a	r value ^b					
Tibialis posterior	Transverse	0.253	0.115	0.100	0.166	0.230	0.228	0.698	-0.039	0.257	0.114	0.541	0.620
	Anteroposterior	0.027	0.221	0.131	0.152	0.006	0.271	0.780	0.028	0.273	0.111	0.373	0.090
	Area	0.029	0.219	0.026	0.222	0.001	0.340	0.910	-0.011	0.155	0.143	0.339	0.097
Flexor digitorum longus	Transverse	0.044	0.202	0.013	0.248	0.001	0.326	0.707	-0.038	0.306	0.103	0.766	0.030
	Anteroposterior	0.541	0.062	0.452	0.076	0.229	0.121	0.181	0.135	0.671	0.043	0.251	0.116
	Area	0.055	0.193	0.033	0.213	0.002	0.311	0.424	0.081	0.289	0.107	0.245	0.117
Flexor halluc longus	Transverse	0.007	0.270	0.019	0.234	<0.001	0.379	0.190	0.132	0.763	-0.300	0.750	0.032
	Anteroposterior	0.246	0.117	0.099	0.166	0.032	0.215	0.521	0.065	0.467	0.074	0.310	0.103
	Area	0.040	0.205	0.020	0.232	0.001	0.329	0.296	0.106	0.775	0.029	0.431	0.080

^a Calculated with ANOVA test^b Calculated with Pearson correlation test

the peroneus longus (PL) and brevis (PB) tendons. Our hypothesis is that abnormalities of the ACH tendon, which is centrally located in this retention system of fascia and retinacula, may predispose to abnormalities in neighboring tendons. In short, this study was initiated to search for an association between ACH, peroneal, and medial flexor tendons abnormalities.

Materials and methods

Patient selection

Institutional ethics review board approval was obtained. Between November 1, 2011, and April 1, 2012, 100 MR imaging studies of the ankle from 100 consecutive different patients were selected from our institution's database and were retrospectively examined. Exclusion criteria were bone fracture, previous surgery, severe osteoarthritis, rheumatoid arthritis or other inflammatory arthritides, diabetes mellitus, end-stage chronic renal disease, gout, dyslipidemia, infection, developmental abnormalities of the foot and ankle, or a history of systemic corticosteroid therapy.

Data were gathered from 100 consecutive patients (54 right ankles and 46 left ankles) of which 52 were women and 48 were men, with a mean age at time of imaging of 48 years (range, 17–92 years) and a mean weight of 79 kg (range, 50.80–136.08 kg).

Image protocol

MR images were obtained with four 1.5-T units (Siemens Symphony, GE Twinspeed Excite System, and two GE Signa Echospeed HDX) and a 3.0-T unit (GE Twinspeed). All studies included sequences in the axial, coronal, and sagittal planes with T1 and T2 fat-saturated or PD-weighted image acquisition, a section thickness of 2.5 mm with 0.5 mm interspace thickness, field of view 12×12 cm and matrix size 512×256. A knee coil was centered just anterior to the tibiotalar joint.

In order to try to define the degree of ankle flexion or extension during imaging, an angle was defined according to that described in previous reports based only on conventional radiography. The angle was measured between the long axis of the tibia and the longest anteroposterior diameter of the talus. Unfortunately, these angle measurements have not yet been validated for MR imaging in large controlled trials [1, 14]. In our group, the mean angle was 85° (range, 67°–101°).

Analysis of MR images

MR images were read in consensus by two of the authors (P.C., C.P.) at a workstation with the Impax 6 Agfa Healthcare picture archiving and communication system (PACS). The

compartments housing the ankle tendons were divided into three: the posterior compartment containing the ACH tendon; the lateral compartment containing the PL and PB tendons; and the medial compartment with the tibialis posterior (TP), flexor digitorum longus (FDL), and flexor hallucis longus (FHL) tendons (Fig. 1). The transverse (T) and anteroposterior (AP) diameters of these six tendons were measured and the sectional area was calculated. For the ACH tendon only, the AP and T diameters, measured at its thickest segment, were taken into consideration as available published data have indicated that the area of the tendon is not critical for the diagnosis of tendinosis [15–17]. The peroneal tendons were measured 15 mm above the fibular tip, corresponding to the proximal segment of the peroneal tunnel, where they are kept in place by the superior peroneal retinaculum (Fig. 2) [4]. The medial flexor tendons were measured 6 mm below the level of the talar dome to include the segment of the flexor tendons enclosed by the flexor retinaculum (Fig. 3) [4]. The presence of tendon abnormality including tendinosis, tenosynovitis (not applicable to the ACH tendon), low- and high-grade partial tear, and complete tear involving the ACH, PL, PB, TP, FDL, and FHL tendons was registered after evaluation of the full length of the tendon. Tendinosis was defined as irregularity of the tendon contour and/or intrasubstance intermediate signal in fluid-sensitive sequences, and tenosynovitis was defined as the presence of circumferential fluid within the synovial tendon sheath greater than 3 mm in maximal width [18]. For the ACH, tendinosis was also considered present if the tendon's AP diameter was greater than 0.7 cm, and paratenonitis if there was a halo of high signal about the tendon in fluid-sensitive sequences [16, 19, 20]. For the other ankle tendons (peroneal tendons and medial flexor tendons), as there is no consensus in the literature defining a cut-off diameter for the diagnosis of tendinosis, the only criterion that was used to define tendinosis was the presence of the qualitative features previously noted. Low-grade partial tear was defined as an intrasubstance area of high signal in fluid-sensitive sequences, with or without extension to the tendon surface. High-grade partial tear and complete tear were defined as near full thickness or full thickness discontinuity of the tendon fibers, respectively.

Statistical analysis

The relationship between tendon dimensions from the three different ankle compartments (lateral, medial, and posterior) as well as between tendons from the same compartment was analyzed using Pearson's correlation and the ANOVA tests. These dimensions were also correlated with age, gender, laterality, and weight of each patient also using Pearson's correlation and the ANOVA tests. The strength of the correlation was quantified according to the r value, and a p value <0.05 was considered as a statistically significant difference.

The association between the presence of qualitative abnormality among the several tendons was analyzed using the Chi-square test (χ^2), and a p value <0.05 was considered as statistically significant. The association between the presence of qualitative abnormality in the ACH and the diameters and sectional area of the other ankle tendons was analyzed using the t test, and a p value <0.05 was considered as statistically significant.

Results

Quantitative results

The values for the mean, 10th, 50th (median) and 90th percentiles, ranges and standard deviation of the diameters, and areas of all the studied tendons are shown in Table 1.

Results of statistical analysis (Pearson's correlation and ANOVA) (Tables 2, 3, 4, and 5) for the relationship between the diameters of the ankle tendons revealed a statistically significant correlation between all the tendons in at least one of the diameters and/or areas, except for the PB tendon. No correlation could be found between the dimensions of the PB tendon and any of the other tendons dimensions ($p>0.05$).

Intracompartmental analysis between the dimensions of the two peroneal tendons showed a positive correlation between at least one of the diameters and/or areas of both tendons ($p<0.018$). The same was also demonstrated among

Table 4 Relationship between the dimensions of the peroneal tendons

	Diameter/area	Peroneus brevis tendon					
		Transverse		Anteroposterior		Area	
		p value ^a	r value ^b	p value ^a	r value ^b	p value ^a	r value ^b
Peroneus longus tendon	Transverse	<0.001	0.396	0.702	0.039	0.018	0.237
	Anteroposterior	0.017	-0.238	<0.001	0.342	0.111	0.160
	Area	0.524	0.064	0.005	0.280	0.005	0.277

^a Calculated with ANOVA test

^b Calculated with Pearson correlation test

Table 6 Relationship between tendons diameters/area and age, gender, side and weight

Tendons	Diameter/area	Age		Gender		Side		Weight ^a	
		<i>p</i> value ^b	<i>r</i> value ^c	<i>p</i> value ^b	<i>r</i> value ^c	<i>p</i> value ^b	<i>r</i> value ^c	<i>p</i> value ^b	<i>r</i> value ^c
Achilles	Transverse	0,002	0.309	0.005	0.281	0.119	−0.134	0.725	0.036
	Anteroposterior	0,002	0.300	0.297	0.105	0.213	−0.126	0.434	0.079
Peroneus longus	Transverse	0,504	0.068	0.960	0.167	0.878	−0.016	0.391	0.087
	Anteroposterior	0,640	0.047	0.540	0.193	0.499	−0.068	0.497	0.069
	Area	0,485	0.071	0.006	0.275	0.637	−0.048	0.253	0.115
Peroneus brevis	Transverse	0,143	0.148	0.534	0.063	0.215	−0.125	0.100	0.166
	Anteroposterior	0,419	0.082	0.788	0.027	0.383	0.088	0.698	0.039
	Area	0,164	0.140	0.671	0.043	0.977	−0.003	0.257	0.114
Tibialis posterior	Transverse	0,249	0.114	0.619	−0.500	0.174	0.137	0.131	0.152
	Anteroposterior	0,724	0.036	<0.001	0.448	0.212	−0.126	0.780	0.028
	Area	0,255	0.115	0.015	0.242	0.945	0.007	0.273	0.111
Flexor digitorum longus	Transverse	0,536	0.063	0.021	0.231	0.602	−0.059	0.910	0.011
	Anteroposterior	0,435	0.079	0.007	0.27	0.356	0.093	0.155	0.143
	Area	0,193	0.131	<0.001	0.348	0.121	−0.156	0.707	0.038
Flexor halluc longus	Transverse	0,009	0.260	<0.001	0.396	0.063	−0.186	0.306	0.103
	Anteroposterior	<0.001	0.379	0.458	0.075	0.326	−0.099	0.541	0.062
	Area	<0.001	0.380	0.005	0.281	0.098	−0.167	0.452	0.076

^a Data on weight was available only from 68 patients

^b Calculated with ANOVA test

^c Calculated with Pearson correlation test

Discussion

Our results indicate that there is a positive correlation between the AP diameter of the ACH tendon (indicative of tendinosis) and the diameters and area of the PL tendon and the three medial compartment tendons (TP, FDL, and FHL tendons). Subjects with a larger AP diameter of the ACH tendon revealed PL, TP, FDL, and FHL tendons with larger diameters and sectional areas. Furthermore, the medial ankle tendons and the PL tendon also had a positive correlation with regard to their diameters and areas, with few exceptions in some of the measurements. This positive correlation was also found when the medial compartment tendons were individually assessed and compared to each other.

Based on our data, there seems to exist a link between the sectional size of the various ankle tendons. Therefore, a subtle abnormality of one of the tendons, reflected by an increase in its diameter, is very frequently accompanied by similar changes in tendons both in the same compartment and in the other two ankle compartments. This was shown in our study for all tendons except for the PB tendon. The fact that none of the measurements related to the PB tendon correlated with any of the other tendons' dimensions ($p > 0.05$) may be explained by the variability of its sectional shape, which makes it difficult to define its exact diameters and area. The frequent finding of a split-type tear without

tendinosis-related diameter increase, instead of the more typical diameter increase that occurs in tendinosis of the other ankle tendons, could also be an explanation since this split-type tear of the PB usually decreases the tendon diameter and area.

Several observations and potential limitations in this study should be emphasized. Based on available literature, the ACH tendon size seems to be directly related to lean body mass and total body mass and, further, women seem to have slightly thinner ankle tendons than men, but the difference has not been found to be statistically significant [21, 22]. We could not find any studies correlating height, weight, or body mass index of persons with the cross-sectional diameters of the peroneal tendons or the medial flexor tendons. Nevertheless, to avoid this possible bias, the age, gender, and weight of the subjects and laterality of the ankle being studied were also analyzed with the purpose of trying to establish the statistical independence of these variables. Data regarding weight could be retrieved for 68 of the subjects. The statistical analysis did not show any relationship between the weight of the subjects and the diameter of the tendons, which makes it less likely that the correlations found between the tendon diameters could be the result of weight bias. Since only the ACH and the FHL tendons showed a positive correlation with the age of the patient, the presence of bias due to this relationship is also very unlikely.

Table 7 Relationship between the incidence of injury in ankle tendons

Medial flexors x Peroneals		Peroneals		TOTALS
		Normal	Injury	
Medial flexors	Normal	38	45	83
	Injury	3	14	17
	TOTALS	41	59	100
P - 0.032*				
Peroneus longus x Peroneus brevis		Peroneus brevis		TOTALS
		Normal	Injury	
Peroneus longus	Normal	41	24	65
	Injury	11	24	35
	TOTALS	52	48	100
P - 0.002*				
Achilles x Peroneals		Peroneals		TOTALS
		Normal	Injury	
Achilles	Normal	24	32	56
	Injury	17	27	44
	TOTALS	41	59	100
P - 0.670*				
Achilles x Medial flexors		Medial flexors		TOTALS
		Normal	Injury	
Achilles	Normal	49	7	56
	Injury	34	10	44
	TOTALS	83	17	100
P - 0.177*				

*Calculated with Chi-square tests

Male gender correlated positively with the tendons' dimensions but, given that our sample was almost evenly divided with 52 females and 48 male subjects, a meaningful influence of this factor on our conclusions is also very unlikely.

The position of the foot, namely, the degree of flexion or extension, at the ankle, could eventually influence the tendons' diameters, though no controlled studies have been conducted on the subject. By using five different MR units and different water-sensitive sequences, some minor degree of measurement variation is also expected, but also on this subject no conclusive data has been published.

To reduce even more the measurement related bias just indicated (due to age, gender, weight, laterality, and ankle position), we attempted to define a direct association only of the presence of qualitative abnormalities in the different

tendons and a statistically significant association was found between the medial flexor and the peroneal tendons and also between the PB and PL tendons, meaning that subjects with tendinosis with altered signal and contour irregularity or with tendon tear in one of the medial tendons had a higher likelihood of showing tendinosis or tearing in one of the peroneal tendons, with the opposite also true. Although a statistically significant association could not be shown between the presence of abnormalities in the ACH tendon and in the other tendons based exclusively on qualitative assessment, a clear trend was present, with a higher frequency of abnormalities in the peroneal and medial tendons in subjects with ACH paratenonitis, tendinosis or tendon tears. A significant statistical association was in fact shown but only when the presence of ACH tendon qualitative abnormalities was correlated to the diameters and areas of all of the ankle

Table 8 Relationship between injury of the Achilles tendon and the dimensions of the other tendons

Tendon measurement (cm)		Achilles tendon with injury ^a	Achilles tendon without injury	<i>p</i> ^b
Peroneus longus	Transverse	0.707	0.644	<0.05
	Anteroposterior	0.443	0.389	<0.05
	Area	0.246	0.193	<0.01
Peroneus brevis	Transverse	0.663	0.631	>0.05
	Anteroposterior	0.329	0.274	>0.05
	Area	0.163	0.128	>0.05
Tibialis posterior	Transverse	0.526	0.453	<0.01
	Anteroposterior	1.089	1.005	<0.05
	Area	0.449	0.356	<0.01
Flexor digitorum longus	Transverse	0.538	0.453	<0.01
	Anteroposterior	0.438	0.382	<0.05
	Area	0.176	0.133	<0.01
Flexor halluc longus	Transverse	0.590	0.501	<0.01
	Anteroposterior	0.423	0.348	<0.01
	Area	0.197	0.139	<0.01

^a Presence of criteria for paratenonitis, tendinosis, or tearing in MR imaging

^b Significance calculated with *t* test

tendons (once again with the exception of the PB tendon). Subjects with a qualitatively abnormal ACH tendon revealed PL, TP, FDL, and FHL tendons that had larger AP and T diameters and larger sectional areas than subjects with normal ACH tendons. This strongly supports the idea that there is a link between abnormality in the ACH tendon and in all of the other ankle tendons.

With regard to the explanation of this link, a possible role of the retinacula in maintaining the structural equilibrium between the three ankle compartments should be considered. Indeed, a complex relationship between the retinacula and adjacent tendons may hold the key to tendon function and integrity and explain the association of abnormalities of the various tendon groups. Nevertheless, several confounding factors cannot be ignored and can be responsible for the present results. Some were already addressed, and others inherent to the study protocol like patient selection and image reading and measuring biases as well as the limited number of the sample can limit the extent of our conclusions.

Conclusions

A statistical correlation was found between the diameters and sectional areas of most of the ankle tendons as well as between qualitative abnormalities on MR images of these tendons. This association seems to indicate that abnormalities in one of the tendons may influence the integrity of the

other tendons perhaps on the basis of a retinacular and fascial system that connects them. Future research in this area should be pursued with larger samples and focusing on tendon and retinacular relationship.

Disclosure The authors declare that they have no conflicts of interest.

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