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MRI findings of spring ligament injury: association with surgical findings and flatfoot deformity

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Abstract

Background: Spring ligament injury is an important cause for flatfoot deformity; however, reliability of magnetic resonance imaging (MRI) findings of spring ligament injury is still ambiguous.

Purpose: To investigate the reliability of MRI findings for the diagnosis of spring ligament injury.

Material and methods: Forty-three cases with spring ligament injury proven by surgery and 29 control cases were enrolled. The spring ligament complex was demonstrated on proton density-weighted images reconstructed from 3D-isotropic MRI data. The presence of waviness, discontinuity, and abnormally high signal intensity of the spring ligament complex was evaluated by two radiologists in cooperation. Also, injury of the posterior tibial tendon (PTT) on MRI and the lateral talo-1st metatarsal angles on weight-bearing X-rays were evaluated.

Results: Discontinuity and abnormally high signal intensity of the superomedial calcaneonavicular ligament (SmCNL) on MRI were more frequently observed in patients with spring ligament injury than in controls ($p < 0.001$). Discontinuity and abnormally high signal intensity of the SmCNL were found more often in the PTT injury group than in those without ($p < 0.001$). The talo-1st metatarsal angle was greater in patients with discontinuity and abnormally high signal intensity of the SmCNL on MRI than in patients without these findings ($p < 0.001$).

Conclusion: Discontinuity and abnormally high signal intensity are reliable MRI findings for spring ligament injury and related disorders, such as flatfoot deformity and PTT injury.

Keywords

MR imaging, spring ligament, flatfoot deformity, posterior tibial tendon

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Introduction

The spring ligament complex originates on the calcaneus and inserts into the navicular bone. It consists of three ligaments, the superomedial calcaneonavicular ligament (SmCNL), the medioplantar oblique calcaneonavicular ligament (MpoCNL), and the inferoplantar longitudinal calcaneonavicular ligament (IplCNL). The spring ligament complexes together with the posterior tibial tendon (PTT) are the most important stabilizers for the talonavicular joint and longitudinal arch of the foot. Thus, injury of the complex often results in flatfoot deformity.[1–12]

Recently, reconstruction of the spring ligament has been considered a viable surgical treatment for flatfoot deformity.[10,11] In addition to physical examinations, radiological assessment is important for preoperative evaluation of spring ligament injuries and their severity. X-rays and magnetic resonance imaging (MRI) are

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also commonly used for assessing flatfoot deformities. Particularly, MRI is used frequently to evaluate the abnormalities of soft tissues, such as the spring ligament complex and the PTT.[1–5] The SmCNL is considered the most important ligament of the spring ligament complex and the single ligament that is observed directly during surgery. A few previous reports have discussed MRI findings of spring ligament injury. According to these, diagnostic MRI findings of SmCNL injury include abnormally high signal intensity on T2-weighted or proton density (PD) images, thickening (>5–6 mm), thinning (<2 mm), waviness, and discontinuity.[1–5] However, it remains unclear which of these MRI findings are the most reliable for diagnosing spring ligament injuries. Also, the relationship between PTT injury and MRI findings of spring ligament injury has not been fully investigated.

On foot weight-bearing X-rays, the lateral talo-1st metatarsal angle (Meary's angle) is commonly used to assess flatfoot deformity. A lateral talo-1st metatarsal angle less than 4° is considered normal, and an abnormally large angle often indicates flatfoot deformity.[9,12] Indeed, Lin et al. have described that an abnormally large talo-1st metatarsal angle (>10°) is associated with PTT injury on MRI.[8] However, considering the relationship between flatfoot deformity and spring ligament/PTT injuries, it can be predicted that there would be some differences in the talo-1st metatarsal angles between patient groups with and without MRI findings of spring ligament injury and PTT injuries.

Thus, the aims of this study were (i) to identify the most frequent MRI finding for the diagnosis of spring ligament injury, based on surgical findings; (ii) to evaluate the relationship between PTT injury and MRI findings of spring ligament injury; and (iii) to clarify the differences in the lateral talo-1st metatarsal angles between patient groups with and without PTT/spring ligament injury.

Material and methods

This retrospective study was conducted with the approval of the Institutional Review Board (IRB) at our institution. Written informed consent from the enrolled patients was waived by the IRB.

Patients

(i) Patient group with spring ligament injury (43 feet)

By reviewing the medical record database of our institution, 65 feet of 63 patients who underwent 3D-isotropic MRI and subsequent orthopedical surgery observing the spring ligaments between January 2010 and March 2019 were identified initially. Seventeen patients were excluded for a previous history of surgery ($n = 3$), poor image quality of the MRI ($n = 12$), or presence of inflammation/infection that affected the foot joint ($n = 2$). Subsequently, surgical records for 48 feet of 46 patients were reviewed carefully. Among them, 43 feet of 41 patients had surgically proven injury of the SmCNL. The remaining five feet (five patients) did not have SmCNL injury proven at surgery. Thus, 43 feet of 41 patients were diagnosed with SmCNL injury and categorized as a patient group with spring ligament injury (34 women, 7 men; age range, 20–80 years; mean age, 60 years).

(ii) Control group without spring ligament injury (29 feet)

A control group without spring ligament injury was identified to compare with the injury group. The control group consisted of two different subgroups: (1) the five patients who did not have spring ligament injury at surgery described above and (2) 24 patients who underwent 3D-isotropic MRI and were not considered to have spring ligament injury. For the second subgroup, 91 patients (age >18 years old) who underwent MRI of the foot for various reasons between January 2010 and March 2019 were identified initially. The conditions for MRI scanning varied, such as anterolateral impingement, osteochondral lesion of the talus, or lateral collateral ligament injury. From the 91 patients, 67 patients were excluded for the following reasons: medial foot pain that may have been caused by spring ligament injury ($n = 45$), poor image quality ($n = 5$), a previous history of surgery ($n = 9$), a history of trauma in the past one month ($n = 3$), and a large talo-first metatarsal angle (>4°) that may have been caused by spring ligament injury ($n = 5$). A total of 29 feet of 29 patients were ultimately selected for the control group (12 women, 17 men; age range, 18–73 years; mean age, 41 years).

Characteristics of the patient and control groups are summarized in Table 1.

MRI scans

MRI scans were performed with a 1.5-T magnet scanner (Achieva; Philips Healthcare, Best, the Netherlands) in 36 examinations or a 3.0-T magnet (Ingenia; Philips Healthcare) in 36 examinations by using one of the following surface coils: Flex S coil (70 mm of inner diameter, 2 channel), knee coil (8 channel), or a dedicated extremity coil (8 channel) supplied by the manufacturer. Ten examinations were done in a prone position, two were scanned in a right lateral decubitus position, and 60 were in a supine position with maximum plantarflexion of the ankle joint to

Table 1. Patient characteristics for the group of surgically proven injury of the superomedial calcaneonavicular ligament (SmCNL) and the control group.

	SmCNL injury (43 feet)	Control (29 feet)
Sex		
Male	8	17
Female	35	12
Age		
Mean (range)	60 (20–80)	41 (18–73)
Condition for MRI		
Flatfoot deformity	40/43	2/29
Symptomatic accessory navicular bone	3/43	3/29
Ankle impingement	0/43	12/29
Osteochondral lesion of the talus	0/43	5/29
Lateral collateral ligament injury	0/43	7/29

MRI: magnetic resonance imaging.
The control group includes five patients who were eventually diagnosed not to have SmCNL injury at surgery, although they were suspected preoperatively to have had injury. Forty-three feet in 41 patients were included in the SmCNL injury group.

minimize the magic angle effect. Volumetric data were obtained using a volumetric isotropic T2-weighted acquisition technique with a field of view of 100–120 mm. The imaging parameters for the 3.0-T scanner were: repetition time, 1000–1200 ms; echo time, 110–120 ms; echo train length, 27; number of averages, 1; slice thickness, 0.6 mm; slice gap, 0.3 mm; and refocusing control radiofrequency pulse, 70°. For the 1.5-T scanner, the parameters were: repetition time, 1000–1200 ms; echo time, 110–120 ms; turbo spin echo factor, 30; number of averages, 1; slice thickness, 0.6 mm; slice gap, 0.3 mm; and refocusing control radiofrequency pulse, 40°.

Sagittal 3D isotropic PD images were obtained with a reconstruction voxel size of $0.6 \times 0.6 \times 0.6$ mm and were shown in arbitrary planes using a commercially available workstation (Ziostation2, Ziosoft Inc, Tokyo, Japan).

Image analysis

MR images were evaluated by two radiologists (7 and 33 years of experience in musculoskeletal radiology) in cooperation using the commercially available workstation (Ziostation2). They were blinded to the patients' medical records. The presence or absence of abnormal MRI findings in the spring ligament complex (SmCNL, MpoCNL, and IplCNL; Figs. 1 to 3) was judged by waviness, abnormally high signal intensity, and discontinuity. Also, the thickness of the SmCNL was measured on the workstation.

PTT injury was evaluated on the same MRI images used for the assessment of spring ligament injury. The presence or absence of PTT injury was determined by the same two radiologists in cooperation based on the criteria of abnormally high signal intensity, thickening, and/or an obvious tear.

For the assessment of flatfoot deformity, the talo-1st metatarsal angle was measured on the lateral view of foot X-rays for all enrolled subjects (both spring ligament injury group and control group). The angle was created by two lines: the line drawn from the center of the longitudinal axis of the talus, and the line drawn from the center of the longitudinal axis of the first metatarsal bone. The average interval between X-rays and MRI was 33 days. X-rays were performed with a Fuji FCR Profect CS (Fujifilm Medical, Tokyo, Japan) for 20 feet, a Kodak DirectView CR 850 (Eastman Kodak Company, New York, USA) for 7 feet, or CXDI Series with Control Software NE (Canon Medical Systems, Tochigi, Japan) for 45 feet. All X-rays were obtained at a dose of 50 kVp and 2–4 mAs.

Statistical analysis

Continuous variables were expressed as the mean $\pm$ standard deviation (SD). All statistical analyses were done using JMP 12.0 software (SAS Institute, Cary, NC, USA).

We used Chi-square and Mann–Whitney tests to evaluate the differences between groups: (i) the differences in MRI findings of the spring ligament complex between the SmCNL injury group and the control group; (ii) the difference in the spring ligament abnormalities (at surgery and on MRI) between groups with and without PTT injury on MRI; (iii) the differences in the lateral talo-1st metatarsal angle between groups with and without SmCNL injury (at surgery and on MRI) or PTT injury (on MRI). A p value of < 0.05 was considered significant.

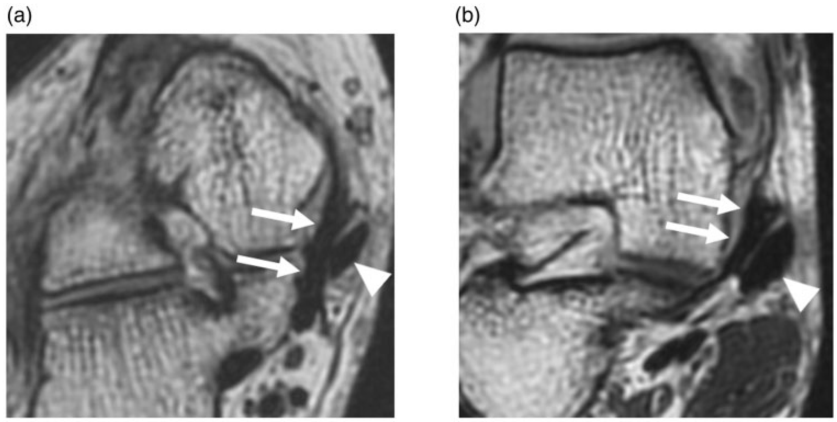

Fig. 1. Normal magnetic resonance imaging (MRI) appearance of the superomedial calcaneonavicular ligament (SmCNL, arrows) and the posterior tibial tendon (PTT, arrowheads). (a) Oblique axial view; (b) coronal view.

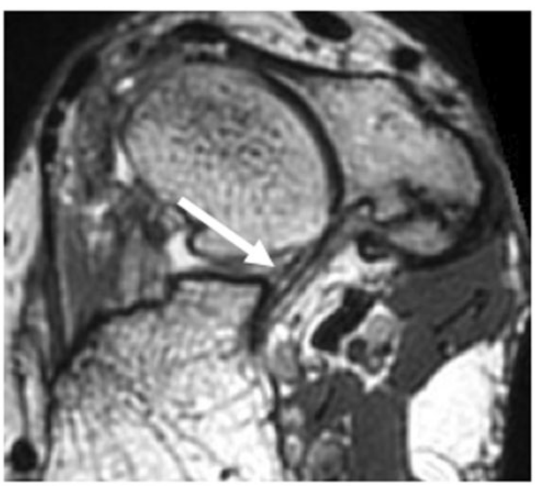

Fig. 2. The normal medioplantar oblique calcaneonavicular ligament (MpoCNL). An oblique axial image demonstrates the MpoCNL as a bundle of ligament stripes (arrow).

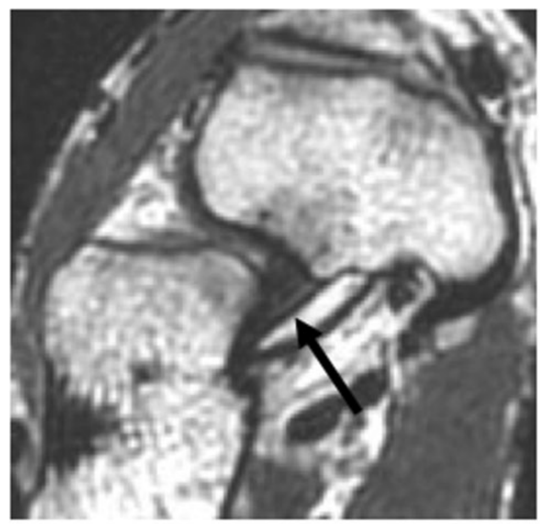

Fig. 3. The normal inferoplantar longitudinal calcaneonavicular ligament (IplCNL). An oblique axial proton image demonstrates the band-like IplCNL (arrow).

Results

Comparison of MRI findings between spring ligament injury and control groups

Discontinuity was observed in the SmCNL of 20 feet (47%; Fig. 4), in the MpoCNL of 2 feet (5%; Supplementary Fig. S1), and in the IplCNL of 4 feet (10%). Waviness of the SmCNL was observed in 15 feet (35%; Fig. 5). Waviness of the MpoCNL (Supplementary Fig. S2) and IplCNL were found in 20 (47%) and 22 feet (54%), respectively. Abnormally high signal intensity was observed in the SmCNL of 33 feet (77%; Fig. 6), in the MpoCNL of 7 feet (16%), and in the IplCNL of 7 feet (17%; Supplementary Figs. S3 and S4).

In the 29 feet of the control group, discontinuity of the ligament was not observed in the SmCNL and IplCNL. Discontinuity of the MpoCNL was observed in only two feet (7%). Waviness was observed in the SmCNL of three feet (10%), in the MpoCNL of six feet (21%), and in the IplCNL of eight feet (28%). Abnormally high signal intensity was observed in the SmCNL of six feet (21%), in the MpoCNL of two feet (7%), and in the IplCNL of one foot (3%). A summary of the MRI findings in the SmCNL injury group and control group is shown as Supplementary Table S1.

Comparisons for the presence of these abnormal MRI findings between the group with surgically proven SmCNL injury and the control group demonstrated that discontinuity and abnormally high signal

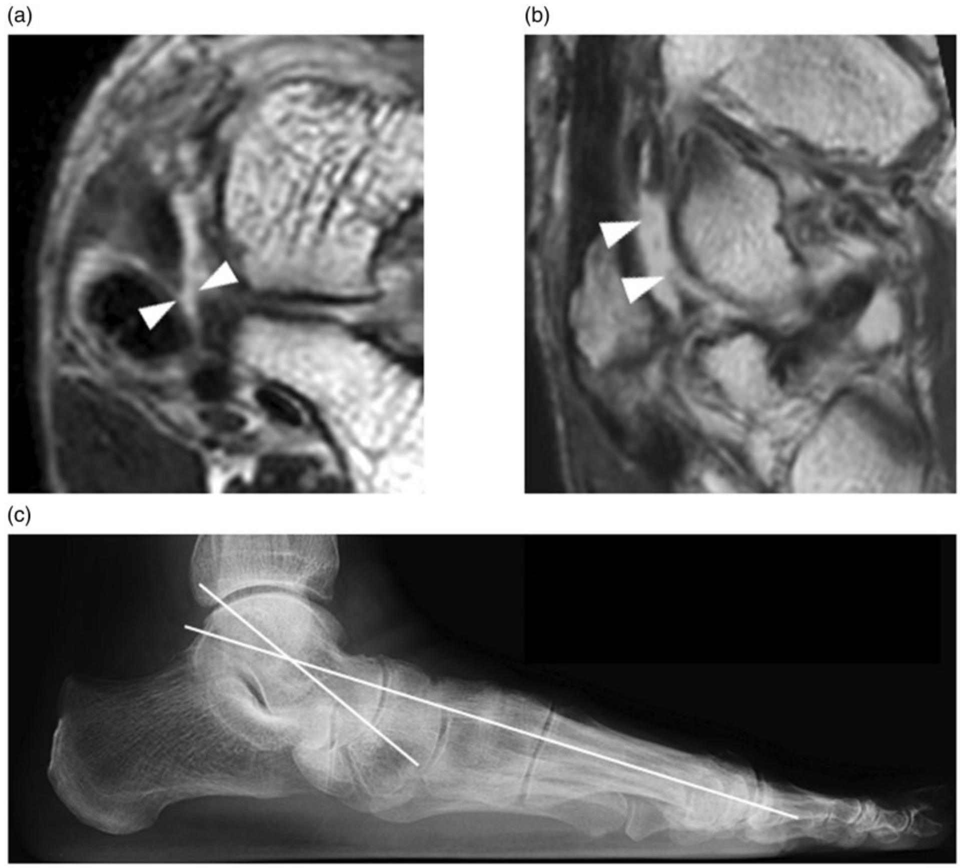

Fig. 4. Discontinuity of the superomedial calcaneonavicular ligament (SmCNL). The torn SmCNL (arrowheads) in a 71-year-old female is demonstrated on an oblique axial image (a), which results in a wide defect of the ligament on a coronal image (b). Weight-bearing lateral X-ray shows abnormally large talo-1st metatarsal angle of 20° (c).

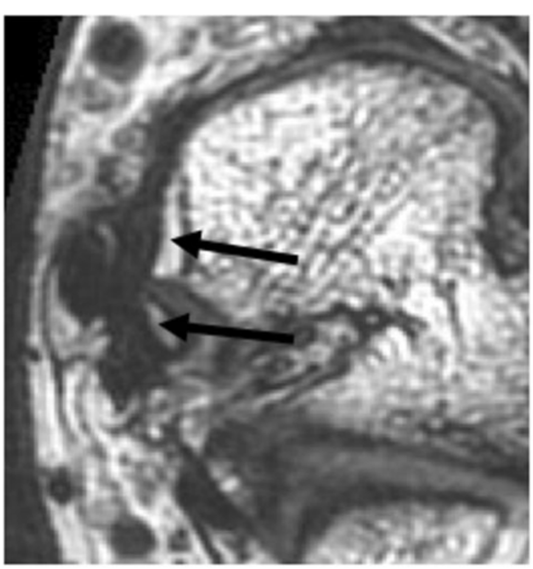

Fig. 5. Waviness of the superomedial calcaneonavicular ligament (SmCNL). An oblique image shows the slightly wavy SmCNL (arrows) in a 25-year-old male. The injury of the SmCNL was confirmed by surgery.

Fig. 6. Abnormally high signal intensity of the superomedial calcaneonavicular ligament (SmCNL). The thickened SmCNL (maximum 9 mm) includes high-signal intensity areas internally (arrows) in a 20-year-old female. Injury of the SmCNL was proven by surgery. The patient had an os tibiale externum.

Table 2. Comparison of abnormal MRI findings between the spring ligament injury group and control group.

	Differences in prevalence of MRI findings between groups with and without SmCNL injury (by surgery)		
Abnormal MRI findings	SmCNL	MpoCNL	IplCNL
Waviness	<0.05	<0.05	<0.05
High signal intensity	<0.001	NS ($p = 0.22$)	NS ($p = 0.06$)
Discontinuity	<0.001	NS ($p = 0.69$)	<0.05

SmCNL: superomedial calcaneonavicular ligament; MpoCNL: medioplantar oblique calcaneonavicular ligament; IplCNL: inferoplantar longitudinal calcaneonavicular ligament; NS: not significant.
Chi-square tests were used to assess the relationship between the presence of abnormal MRI findings and surgically proven injury of the SmCNL

Table 3. Differences in spring ligament findings between groups with and without PTT injury on MRI.

	Difference in spring ligament findings between groups with and without PTT injury		
	SmCNL	MpoCNL	IplCNL
At surgery			
SmCNL injury	<0.001	–	–
Abnormal MRI findings			
Waviness	<0.05	<0.05	NS ($p = 0.11$)
High signal intensity	<0.001	NS ($p = 0.52$)	<0.05
Discontinuity	<0.001	NS ($p = 0.77$)	<0.05

PTT: posterior tibial tendon; MRI: magnetic resonance imaging; SmCNL: superomedial calcaneonavicular ligament; MpoCNL: medioplantar oblique calcaneonavicular ligament; IplCNL: inferoplantar longitudinal calcaneonavicular ligament; NS: not significant.
Chi-square tests were used to compare the presence of PTT injury on MRI and injury of the spring ligament complex.

intensity of the SmCNL were more frequently observed in the group with SmCNL injury than in the control group ($p < 0.001$; Table 2).

The maximum thickness of the SmCNL was significantly greater in the SmCNL injury group (5.23 ± 1.57 mm) than in the control group (4.48 ± 1.06 mm; $p < 0.05$).

Differences in spring ligament findings between groups with and without PTT injury on MRI

In the group with MRI-based PTT injury, discontinuity and abnormally high signal intensity of the SmCNL on MRI were more frequently observed than in the group without PTT injury ($p < 0.001$). Significant differences in the presence of waviness in the SmCNL and MpoCNL, and the presence of discontinuity and high signal intensity in the IplCNL also were observed between the groups with and without PTT injury ($p < 0.05$; Table 3).

Differences in the lateral talo-1st metatarsal angles between the groups with and without SmCNL/MRI-based PTT injuries

The lateral talo-1st metatarsal angle was significantly greater in the groups with (i) SmCNL injury at surgery than in those without ($p < 0.001$); (ii) discontinuity of the SmCNL on MRI than in those without ($p < 0.001$); and (iii) high signal intensity of the SmCNL on MRI than in those without ($p < 0.001$; Table 4). No significant difference was found between groups with and without waviness of the SmCNL on MRI. The angle was also significantly greater in the group with PTT injury on MRI than in those without ($p < 0.001$).

Discussion

In this study, we evaluated MRI findings of the spring ligament complex and found that abnormally high signal intensity and discontinuity of the SmCNL on MRI are: (i) more frequently found in the SmCNL injury group than in the control group (without SmCNL injury); (ii) more frequently found in the group with PTT injury (on MRI) than in the group without; and (iii) related to the abnormally large talo-1st metatarsal angle, which suggests flatfoot deformity. Based on these observations, we strongly believe that among several abnormal MRI findings, the abnormally high signal intensity and discontinuity of the SmCNL are the most reliable parameters to predict SmCNL injury and are related to PTT injury and flatfoot deformity. Abnormal thickening and waviness of the spring ligament complex can be considered to be less reliable than discontinuity and abnormally high signal intensity of the SmCNL.

Table 4. Difference in lateral the talo-1st metatarsal angle between groups with and without SmCNL/PTT injuries.

	Presence	Absence	*p* value
At surgery			
SmCNL injury	$18.91° \pm 11.75°$	$1.31° \pm 3.08°$	<0.001
Abnormal MRI findings			
SmCNL-waviness	$15.55° \pm 14.62°$	$10.57° \pm 11.86°$	NS ($p = 0.17$)
SmCNL-discontinuity	$18.15° \pm 11.20°$	$9.38° \pm 12.47°$	<0.001
SmCNL-high signal intensity	$16.33° \pm 12.08°$	$6.48° \pm 11.39°$	<0.001
PTT injury	$16.41° \pm 10.90°$	$5.74° \pm 12.47°$	<0.001

PTT: posterior tibial tendon; MRI: magnetic resonance imaging; SmCNL: superomedial calcaneonavicular ligament; NS: not significant.
Mann–Whitney tests were used to compare the talo-1st metatarsal angles between the groups with and without abnormalities at surgery or on MRI.

Previous literature has reported several abnormal MRI findings for SmCNL injuries. Generally, increased signal intensity on T2-weighted or PD images, waviness, discontinuity, and thickening of the ligament are considered to be common MRI findings suggesting injury.[2–5] In the current study, similar tendencies were also found in the surgically proven SmCNL injury group: high signal intensity on the PD image (77%), discontinuity (47%), and waviness (35%). This indicates that our study population was basically similar to patients previously reported. However, by comparing with the control group, large differences in the prevalence of MRI findings between the SmCNL injury group and control group were found for abnormally high signal intensity and discontinuity of the SmCNL (both $p < 0.001$). In contrast, waviness was also found in the control group to some extent, which resulted in a relatively small difference in the prevalence ($p < 0.05$). These observations suggest that it is important to compare MRI findings in the group with spring ligament injury and in the group without to obtain accurate knowledge about the prevalence of the MRI findings both in the patient and control groups. Particularly, comparing to discontinuity of the spring ligament that directly suggests malfunction of the ligament, it is notable that abnormally high signal intensity of the ligament also is related to ligament injury and flatfoot deformity, which should provoke more attention when interpreting MR images of the spring ligament complex.

The previous literature also has reported that thickening of the SmCNL (>5 or 6 mm) is a useful MRI finding to predict SmCNL injury.[2–5] An anatomical study by Taniguchi et al. has reported that thickness of the normal SmCNL is considered to be 4.8 ± 1.4 mm,[6] which is very close to the 'abnormal' 5 mm thickness on MRI and thereby indicates the difficulty of setting a clear threshold to diagnose abnormal thickening. Indeed, in our study, the mean thickness of the SmCNL in the injury group was 5.23 ± 1.57 mm. Although the mean thickness exceeded 5 mm, a large standard deviation of 1.57 mm clearly implies that both thickening and thinning occur in patients with SmCNL injury. Besides the thickening, it is reasonable that the chronic degenerative process of SmCNL injury may progress in the direction of abnormal thinning of the SmCNL, particularly when a severe tear or discontinuity of the ligament occurs. Thus, thickness of the SmCNL should be carefully evaluated in daily clinical care, and physicians should be careful not to underestimate the meaning of the thinned spring ligament, which may suggest a precedent injury.

In this study, abnormally high signal intensity and discontinuity of the SmCNL were related to PTT injury on MRI and the large talo-1st metatarsal angle. There are several causes of flatfoot deformity; however, spring ligament injury is considered to be a major cause of flatfoot deformity, particularly when associated with dysfunction or injury of the PTT.[12,13] Flatfoot deformity might occur as a complication of symptomatic accessory navicular bone, which results in degeneration of PTT.[12] Generally, SmCNL injury results in talar head rotation toward the plantar direction, which causes the large talo-1st metatarsal angle and flatfoot deformity. Therefore, it is important to know whether or not MRI findings of spring ligament injury truly relate to flatfoot deformity. In the current study, subjects with high signal intensity or discontinuity of the SmCNL had 2–3 times greater talo-1st metatarsal angles than subjects without these MRI findings, suggesting that these two findings not only indicate the presence of spring ligament injury, but also subsequent flatfoot deformity caused by spring ligament injury.

There are several limitations of this study. First, this study is retrospective and included a small sample size. Second, all patients in the SmCNL injury group underwent surgery to repair the ligament, suggesting that only those with severe SmCNL injury would have been enrolled in this group. The results may have been different if patients with slight SmCNL injuries had been enrolled. Third, the scanning position of the foot/ankle at MRI was not fixed, particularly for the patients in the control group, due to the shape of the coil or the best scanning position for the predicted disorder. This may have influenced some MRI findings of the spring ligament complex, particularly for the evaluation of waviness. Fourth, MRI-based PTT injury consisted of different diagnostic attributes, such as abnormally high signal intensity, thickening, and/or an obvious tear, but only two groups for PTT injury were defined from the MRI (presence or absence of injury). More detailed investigation is recommended to clarify the relationship between spring ligament injury and PTT injury. Fifth, we have not evaluated other stabilizing structures of the foot, such as the deltoid ligament, talocalcaneal ligament, or plantar fascia. Further study is needed to clarify the role of these structures for stabilizing the foot.

In conclusion, high signal intensity and discontinuity of the SmCNL are more reliable MRI findings than other MRI abnormalities for the diagnosis of SmCNL injury, and also are related to flatfoot deformity.

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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