

A Characteristic Magnetic Resonance Imaging Finding to Identify Morton Neuroma: The Slug Sign

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Abstract

Background: Morton neuroma is a common cause of forefoot pain and sensory disturbances, but it is difficult to identify on magnetic resonance imaging (MRI). The aim of this study was to verify the usefulness of a characteristic MRI finding (slug sign) for identifying Morton neuroma and to clarify the relationship between excised neuroma characteristics and preoperative MRI findings.

Methods: Twenty-two web spaces were retrospectively assessed from the second and third intermetatarsal spaces of 11 feet of 10 patients (7 women and 3 men, aged average 59.5 years) who underwent surgical excision of Morton neuroma between 2017 and 2022. Asymptomatic web spaces were used as control. Neuromas with 2 branches of the plantar digital nerves on axial T1-weighted MRI (MRI-T1WI) were considered the slug sign. We investigated the preoperative presence of the slug sign in Morton neuroma and asymptomatic control web spaces. We also investigated the relationship between the maximum transverse diameter of the excised specimen and that estimated on coronal MRI-T1WI.

Results: A total of 15 Morton neuromas were excised and assessed. The slug signs were present in 10 intermetatarsal spaces in 15 web spaces with Morton neuroma whereas the sign was found in 1 intermetatarsal space in 7 asymptomatic web spaces. The sensitivity and specificity for the slug sign to diagnose Morton neuroma was 66.7% and 85.7%, respectively. The positive and negative predictive values were 90.9% and 54.5%, respectively. The mean maximum transverse diameter of excised neuromas was 4.7 mm. The mean maximum transverse diameter of neuromas on coronal MRI-T1WI was 3.4 mm. A significant positive correlation was found between the maximum transverse diameters of excised specimens and diameters estimated on coronal MRI-T1WI ($r=0.799$, $P<.001$).

Conclusion: The slug sign may be a useful indicator of Morton neuroma on MRI to confirm nerve involvement after bifurcation.

Level of Evidence: Level IV, retrospective series.

Keywords: Morton neuroma, T1-weighted MRI, forefoot pain, slug sign

Introduction

Morton neuroma is a degenerative entrapment neuropathy that causes frequent burning, tingling, or numbness between the toes.⁸ These neuromas are commonly located in the third intermetatarsal space (between the third and fourth metatarsal heads) where the medial and lateral branches of the plantar digital nerve form an anastomose, followed by the second intermetatarsal space.¹³ The diagnosis of Morton neuroma is based on clinical assessment.¹⁵ However, ultrasonographic and magnetic resonance imaging (MRI) should be performed in cases where clinical findings are unclear or multiple intermetatarsal spaces may be involved.¹⁵

MRI can help confirm clinical diagnoses as well as determine the size and location of the neuroma and exclude other causes of pain, including stress fractures, synovitis or

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subluxation of the metatarsophalangeal joints, plantar plate tears, and degenerative changes.^{4,7} Although the diagnosis of Morton neuroma is usually established clinically and confirmed using ultrasonography or MRI,^{2,4,19} identifying Morton neuroma remains difficult. In a recent report, the sensitivity and specificity of MRI for the detection of Morton neuroma were 93.6% and 50%, respectively, which remains controversial regarding the usefulness of MRI findings in daily practice.⁵ Therefore, it is important to search for characteristic MRI findings that can help confirm clinical diagnosis of Morton neuroma.

The aim of this study was to verify the usefulness of a characteristic MRI finding (the slug sign) for the identification of Morton neuroma and to assess relationships between excised specimens and preoperative MRI findings.

Materials and Methods

Patients

This retrospective study was approved by the ethics committee of the authors' home institution (approval number: 2210-047). Written informed consent was obtained from all patients. The authors reviewed all patients who underwent surgical excision of Morton neuroma at our institution from November 2017 to February 2022. The procedures were performed by one of the authors. Morton neuroma is typically located on the plantar side between the metatarsal heads on coronal MRI and has been reported to be most visualized on T1-weighted MRI (MRI-T1WI).^{10,22,23} Inclusion criteria for the study required patients to have preoperative MRI-T1WI and clinical evaluation of interdigital tenderness to palpation and dysesthesia of the toes and the record of the maximum transverse diameter of excised specimens. Exclusion criteria included patients with incomplete preoperative MRI-T1WI, clinical evaluation, and the record of the diameter of excised specimens.

All patients received at least 3 months of nonoperative treatment consisting of shoe modifications, orthotics, gastrocnemius and Achilles tendon stretching, rehabilitation, corticosteroid infiltration, and analgesia. Operative treatment was indicated when nonoperative management failed to adequately control symptoms. Surgical neuroma excision was performed via a dorsal approach. After protecting the sensory branches of the superficial peroneal nerve, the interosseous fascia was incised. After exposure of the interosseous muscles, the superficial and deep ligaments were reached. The nerve was resected at least 5 mm proximal and 5 mm distal to the neuroma. The neuroma was then removed and sent for histopathologic examination, which revealed fibromatosis of the interdigital nerve and/or a thickened epineurium in all cases.

MRI Assessment

MRI assessment was performed using a 3-Tesla MRI (MAGNETOM Skyra 3 Tesla; Siemens, Erlangen, Germany) with phased array coils using a conventional T1WI spin-echo sequence (repetition time 450-581 ms, time to echo 10-15 ms, slice thickness 1.5-3 mm). All patients underwent preoperative MRI-T1WI in the supine position with the foot in plantar flexion, and slice thicknesses of 1.5, 2, and 3 mm were used in 5, 3, and 2 patients, respectively. Morton neuroma occurs at the terminal bifurcation of the common plantar digital nerve. We defined neuromas with 2 branches of the plantar digital nerve as the slug sign and investigated the presence of slug signs on preoperative axial MRI-T1WI data (Figure 1, A and B). In diagnosis, we first identify the neuroma at the level of the metatarsophalangeal joint on the coronal slice of MRI-T1WI. Next, we look for a slug sign on the axial slice of the MRI-T1WI. Because the 2 branches of the plantar digital nerve usually run distally and dorsally from their bifurcation, it is important to look for the slug sign slightly dorsally from the centre of the neuroma in an axial plane. We asked a qualified radiologist without knowledge of the patients to read radiologic interpretations of MRIs. Asymptomatic web spaces were used as control in the second or third intermetatarsal space. We also assessed the relationship between the maximum transverse diameter of excised specimens and that of the neuroma on coronal MRI-T1WI (Figure 1).

Statistical Analysis

Statistical analyses were performed using Easy R.⁹ Analysis was started by using the data normality test using the Shapiro Wilk test. In testing the correlation between the maximum transverse diameter of excised specimens and that of the neuroma on coronal MRI-T1WI, the Pearson correlation coefficient is used if the data are normally distributed and the Spearman rank correlation coefficient is used if the data are not normally distributed. $P < .05$ was considered statistically significant. Either correlation coefficients were used for sensitivity analysis.

Results

We included consecutive 11 feet from 7 women and 3 men (mean age, 59.5 years). No patients were excluded in this study. A total of 15 neuromas were excised and assessed during the study time period. Eight neuromas were located in the second intermetatarsal space, and 7 were in the third intermetatarsal space. Four cases had 2 neuromas in both the second and third intermetatarsal spaces. All patients had interdigital tenderness to palpation and dysesthesia of the toes. Overall, slug signs were found in 10 intermetatarsal spaces in 15 Morton neuromas. Seven asymptomatic web

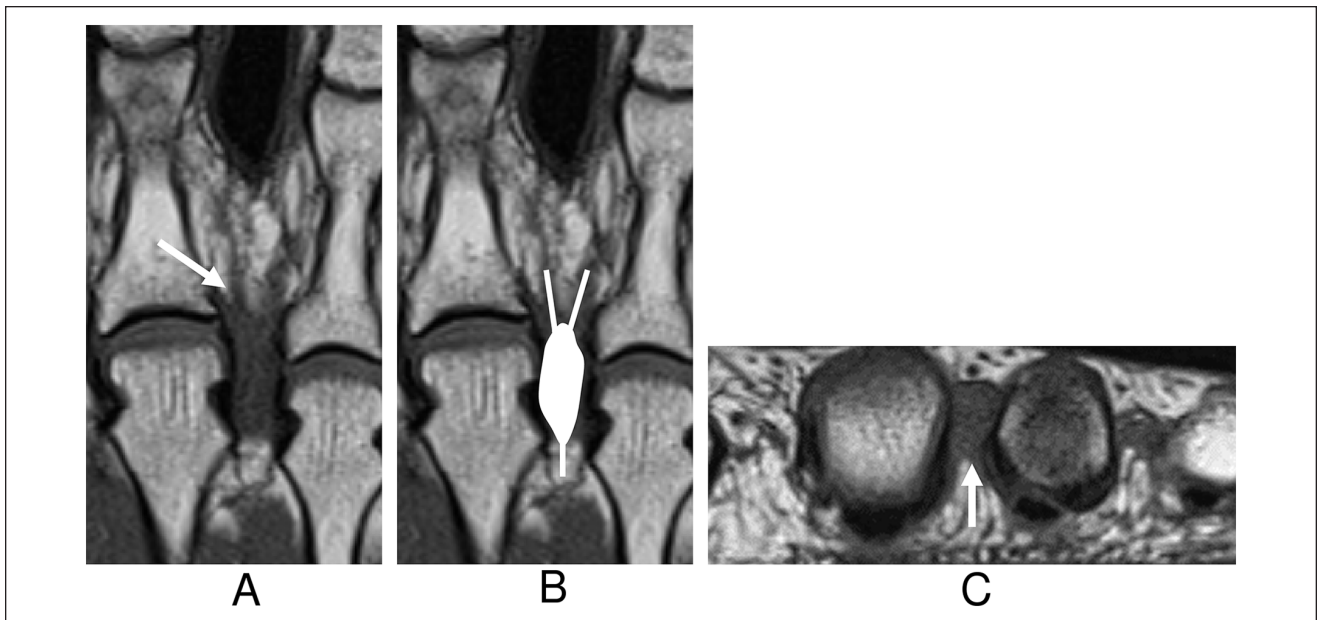


Figure 1. A slug sign of Morton neuroma on T1-weighted magnetic resonance imaging (MRI-T1WI). (A, B) Neuroma with the 2 branches of the plantar digital nerves at the metatarsophalangeal joint on axial MRI-T1WI (arrow and slug-like mass); (C) neuroma in the intermetatarsal space on coronal MRI-T1WI (arrow).

Table 1. Presence of a Slug Sign on MRI-T1WI in Morton Neuroma and Asymptomatic Control Web Spaces.

	Morton Neuroma, n	Asymptomatic Control, n
Slug sign present	10	1
Slug sign absent	5	6

Abbreviations: MRI-T1WI, T1-weighted magnetic resonance imaging.

spaces were used as control in the second or third intermetatarsal space. The slug signs were present in 10 intermetatarsal spaces in 15 web spaces with Morton neuroma; in 7 asymptomatic web spaces, the sign was found in 1 intermetatarsal space (Table 1). The sensitivity and specificity for the slug sign to diagnose Morton neuroma was 66.7% and 85.7%, respectively. In addition, positive and negative predictive values were 90.9% and 54.5%, respectively. In the subanalysis, the slug signs were present in 8 intermetatarsal spaces in 10 neuromas with a diameter of 3 mm or more; in 5 neuromas less than 3 mm in diameter, the sign was found in 2 intermetatarsal spaces. The mean maximum transverse diameter of excised neuromas was 4.7 (range, 2.0-8.0) mm. The mean maximum transverse diameter of neuromas on coronal MRI-T1WI was 3.4 (range, 1.7-6.6) mm. The maximum transverse diameter of the neuroma on coronal MRI-T1WI were normally distributed with $P \geq .05$ whereas that of excised specimens were not normally distributed with $P < .05$, so the analysis continued on Spearman rank

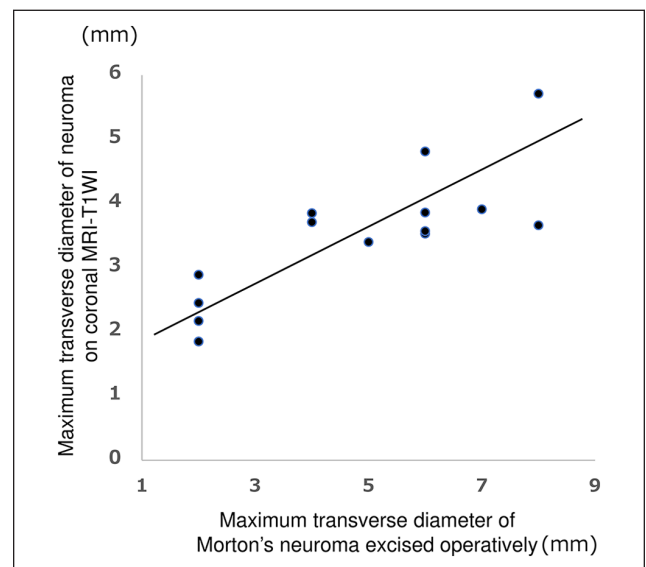


Figure 2. Correlation between maximum transverse diameter of Morton neuroma excised operatively and maximum transverse diameter of neuroma on coronal T1-weighted magnetic resonance imaging (MRI-T1WI).

correlation coefficient. A significant positive correlation was found between the maximum transverse diameter of the excised specimen and that estimated on coronal MRI-T1WI ($r=0.799$, $P < .001$) (Figure 2). The result of sensitivity analysis was similar.

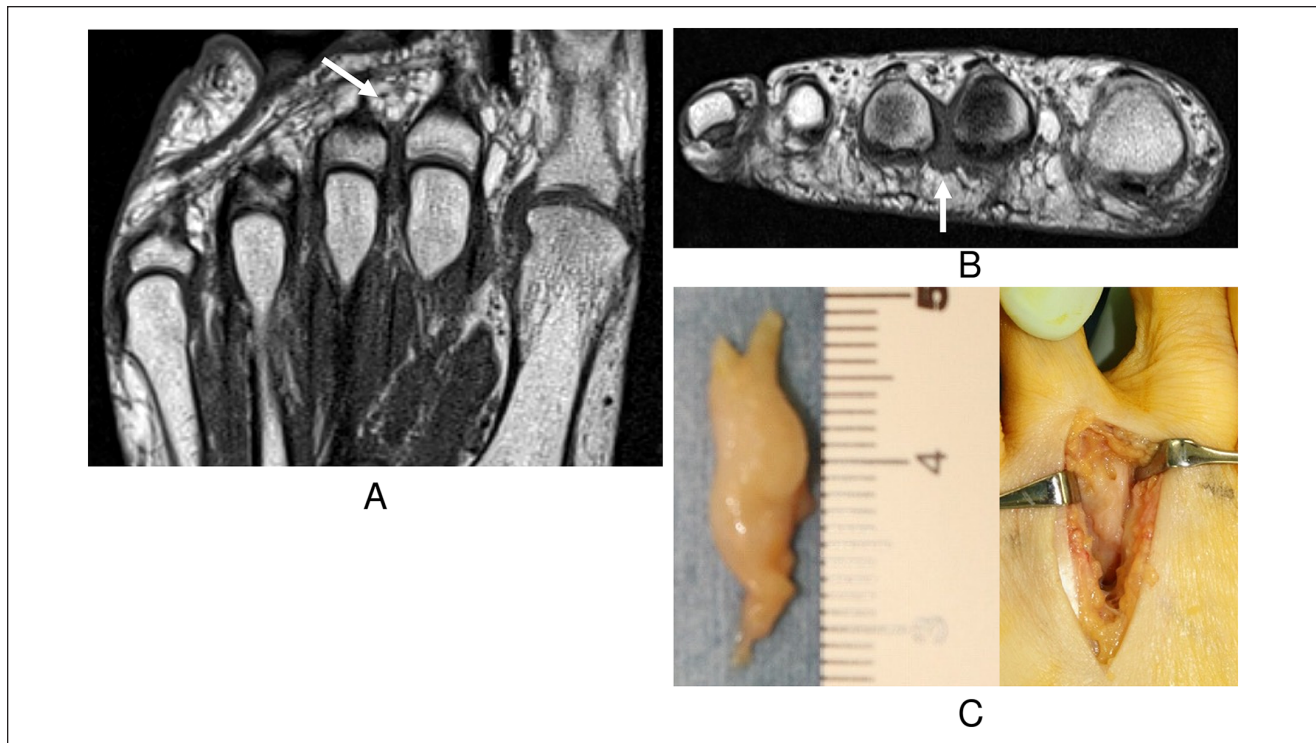


Figure 3. T1-weighted magnetic resonance imaging (MRI-T1WI) and clinical findings in a 58-year-old woman with Morton neuroma. (A) MRI-T1WI (axial); (B) MRI-T1WI (coronal); (C) neuroma excised surgically.

Case Presentation

A 58-year-old woman who was diagnosed with Morton neuroma presented with plantar pain in the second intermetatarsal space. On axial MRI-T1WI, the slug sign was seen in the second intermetatarsal space (Figure 3A, arrow). On coronal MRI-T1WI, the maximum transverse diameter of the neuroma was 4.8 mm (Figure 3B, arrow). The maximum transverse diameter of the surgically excised Morton neuroma was 6.0 mm (Figure 3C).

Discussion

In this study, we confirmed that Morton neuromas often involve the nerve after it bifurcates and that is visible as the slug sign for identifying the neuroma on axial MRI-T1WI. Clinical assessment has been reported to require before imaging, because of the possibility of confounding findings or asymptomatic common digital nerve enlargement.²⁰ The sensitivity and specificity for the slug sign to diagnose Morton neuroma was 66.7% and 85.7%, respectively. In addition, positive predictive value was 90.9%. In some previous reports, the specificity of MRI for the detection of Morton neuroma ranged from 33% to 50%.^{3,5} Thus, the slug sign could be clinically useful to diagnose Morton neuroma because the specificity of slug sign for the neuroma was higher than that in the previous reports.

Morton neuroma is typically located on the plantar side between the metatarsal heads on coronal MRI and has been reported to be most visualized on the MRI-T1WI.^{10,22,23} The sensitivity of MRI for the diagnosis of Morton neuroma has recently been reported to be as high as 80% to 93.6%.^{3,5,15,16,21} However, it is often difficult to identify on MRI. Therefore, we defined a characteristic MRI finding of neuromas with 2 branches of the plantar digital nerves as the slug sign for identifying Morton neuroma on axial MRI. In this study, the slug signs were present in 8 intermetatarsal spaces in 10 neuromas with a diameter of 3 mm or more, whereas in 5 neuromas less than 3 mm in diameter, the sign was found in 2 intermetatarsal spaces. The slug sign can be visualized when the MRI slice is placed at the bifurcation of the 2 branches of the plantar digital nerve that run distally and dorsally from the neuroma; if the slice is not obtained, the slug sign would be negative. In neuromas with a diameter less than 3 mm, the nerves at the bifurcation could be thinner, and the slug sign may be difficult to visualize on MRI.

The diagnosis of Morton neuroma is usually made through patient history and physical examination. The sensitivity of clinical assessment to diagnose histologically confirmed symptomatic interdigital neuroma has been reported to be 100%.⁵ In this study, all patients had interdigital tenderness to palpation and dysesthesia of the toes. However, symptomatology cannot be specific and imaging may be needed to

diagnose the neuroma. A recent report had described that presence of interphalangeal divergence on conventional radiographs is specific to diagnose for Morton neuroma.⁶ In the current study, the identification of neuromas using MRI was accurate as a significant positive correlation was found between the maximum transverse diameter of the excised specimen and that estimated by MRI.

Regarding the association between clinical findings and the size of Morton neuroma, one study reported a mean diameter of 5.3 mm in symptomatic cases and of 4.1 mm in asymptomatic cases.¹ In addition, the mean diameter of neuromas was reported to be 4.5 mm in asymptomatic subjects and 5.6 mm in symptomatic subjects.²³ The diagnosis of Morton neuroma on MRI may be relevant only when the transverse diameter is 5 mm or more and can be correlated to clinical findings.²³ However, some studies show no correlation between symptomatology and the size of Morton neuroma.^{14,19} In the current study, the mean maximum transverse diameter of excised neuromas was 4.7 mm. Larger neuromas could indicate a need for further interventions such as drug injections or neurectomy.¹² Additionally, better results were achieved after excision of neuromas larger than 3 mm in diameter than in cases of neuromas smaller than 3 mm.¹⁸ It is thus important to identify neuromas 3 mm or more in diameter because the diameter of the normal plantar digital nerve is 1 to 2 mm at the level of the intermetatarsal heads.^{10,17}

The current study was limited by its retrospective design and small number of cases. This could limit the generalizability due to a single-center study with subjects of single ethnicity. All neuromas were identified using 3T MRI in this study, which may be the reason why the slug signs were clear even in relatively older patients. In 7 asymptomatic web spaces, the slug sign was present in one intermetatarsal space. The bifurcated nerve might be mimicked by vein in this case. In addition, the MRI slice thickness was not consistent in all cases. It has been reported that a slice thickness of 2 mm or less in all planes of MRI is important for the detection of Morton neuroma.¹¹ In the present study, in 2 patients examined with a 3-mm MRI slice thickness, the slug sign could be identified on the MRI scan. Further studies using standardized MRI slice settings should be performed.

The strength of the current study is that we examined all surgically excised neuromas to evaluate the MRI findings and an independent radiologist confirmed radiologic interpretations of MRIs.

In conclusion, the slug sign may be useful as a clue and a confirmation of nerve involvement after bifurcation in Morton neuroma on MRI.

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Ethical Approval

Ethical approval for this study was obtained from the ethics committee of Okayama University Graduate School (approval number: 2210-047).

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. Disclosure forms for all authors are available online.

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