Foot and Ankle Surgery xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Foot and Ankle Surgery

journal homepage: www.journals.elsevier.com/foot-and-ankle-surgery

Dynamic ultrasound (DUS) versus magnetic resonance imaging (MRI) for the diagnosis of Morton's neuroma: A prospective comparative study

Carlo Biz [a,b,c,*], Filippo Crimì [d], Giovanni Sciarretta [a,b], Alberto Crimì [b], Antonella Dimaggio [a,b], Antonio Corso [d], Raimondo Angelone [d], Emilio Quaia [d], Pietro Ruggieri [a,b,c]

[a] Department of Surgery, Oncology and Gastroenterology DiSCOG, University of Padova, Via Giustiniani 3, 35128, Padova, Italy
[b] Department of Orthopedics and Orthopedic Oncology, Padua University - Hospital, Via Giustiniani 3, 35128, Padova, Italy
[c] Centre for Mechanics of Biological Materials, University of Padova, 35131, Padova, Italy
[d] Institute of Radiology, Department of Medicine DIMED, University of Padova, Via Giustiniani 3, 35128, Padova, Italy

ARTICLE INFO

Article history:
Received 28 July 2026
Received in revised form 25 August 2026
Accepted 10 September 2026

Keywords:
Morton's neuroma
Ultrasound
Magnetic resonance imaging
Forefoot pain
Metatarsalgia
Diagnostic imaging

ABSTRACT

Introduction: Morton's neuroma (MN) is primarily diagnosed clinically, with imaging commonly used for confirmation and differential diagnosis, particularly from intermetatarsal bursitis (IMB). Dynamic ultrasonography (DUS) and magnetic resonance imaging (MRI) performance in detecting MN remains debated. The aim of this study was to compare DUS and MRI using concordant imaging findings, histopathologic confirmation, and clinical follow-up.
Methods: Prospective single-centre comparative study, patients with suspect MN underwent DUS and MRI examinations, interpreted independently by blinded radiologists. Surgical excision with histopathologic confirmation was the reference standard for MN, whereas symptoms resolution after conservative treatment at 12-month follow-up confirmed intermetatarsal bursitis (IMB). Diagnostic performance metrics and receiver operating characteristic (ROC) curves were calculated.
Results: Seventy-six lesions were evaluated (53 MN and 23 IMB). DUS and MRI demonstrated a diagnostic accuracy of 98.68% and 89.47%. The area under the ROC curve was significantly higher for DUS ($P = .0147$).
Conclusion: DUS demonstrated superior diagnostic performance, representing a reliable and cost-effective first-line imaging modality.
Level of evidence: Level II, prospective comparative diagnostic study.

1. Introduction

Morton's neuroma (MN) is a common cause of chronic neuropathic forefoot pain [1,2], and represents a benign perineural fibrosis of the common plantar digital nerve, most frequently affecting the third intermetatarsal space, although the second and, less commonly, the fourth intermetatarsal spaces may also be involved [3].

The term *"Morton's neuroma"* is universally accepted but the condition was described several decades before the publications by Morton [4,5].

Its aetiology is multifactorial, involving repetitive microtrauma, associated with prolonged ambulation or sporting activity, chronic inflammation of the intermetatarsal space (IMS), nerve ischemia, and mechanical entrapment related to biomechanical alterations of the forefoot [6]. Currently, the entrapment theory with a compressive neuropathy of the common plantar digital nerve is the most widely accepted [7].

Patients typically present with neuralgic pain, dysesthesia, burning sensations, or cramping localized to the forefoot. Symptoms often improve after removal of footwear [8]. Other causes of metatarsalgia are intermetatarsal bursitis (IMB), metatarsophalangeal synovitis, plantar plate injuries, stress fractures, joint instability, and rheumatologic or degenerative conditions. On physical examination, clinicians may detect tenderness between the metatarsal heads, sensory alterations between the toes, and occasionally a palpable mass.

* Correspondence to: Department of Orthopedics and Orthopedic Oncology, Department of Surgery, Oncology and Gastroenterology DiSCOG, University of Padova, Via Giustiniani 3, Padua 35128, Italy.
E-mail addresses: carlo.biz@unipd.it (C. Biz), filippo.crimi@unipd.it (F. Crimì), giovanni.sciarretta@studenti.unipd.it (G. Sciarretta), alberto.crimi@aopd.veneto.it (A. Crimì), antonella.dimaggio@aopd.veneto.it (A. Dimaggio), antonio.corso.1@studenti.unipd.it (A. Corso), raimondo.angelone@studenti.unipd.it (R. Angelone), emilio.quaia@unipd.it (E. Quaia), pietro.ruggieri@unipd.it (P. Ruggieri).

https://doi.org/10.1016/j.fas.2026.09.009

Please cite this article as: C. Biz, F. Crimì, G. Sciarretta et al., Dynamic ultrasound (DUS) versus magnetic resonance imaging (MRI) for the diagnosis of Morton's neuroma: A prospective comparative study, Foot and Ankle Surgery, https://doi.org/10.1016/j.fas.2026.09.009

Diagnosis is primarily clinical, with Mulder's test (MT) providing confirmatory support. However, as history and physical examination alone demonstrate variable sensitivity and specificity, imaging studies are required to exclude alternative causes of forefoot pain [9,10].

Dynamic ultrasonography (DUS) and magnetic resonance imaging (MRI) are the most used imaging modalities [6,9,11]. However, previous studies have reported substantial variability in the sensitivity and specificity of Ultrasound (US) and MRI, often related to differences in imaging protocols and the size thresholds used to define a neuroma [12–15].

Several comparative studies and systematic reviews have evaluated the diagnostic performance of US and MRI, reporting comparable accuracy between the two modalities [13–15]. However, most previous studies evaluated conventional imaging protocols, whereas the potential incremental value of a standardised dynamic ultrasound examination, including assessment of MT and lesion compressibility, has been less extensively investigated. Therefore, further prospective comparative studies using standardised imaging protocols remain warranted.

The objective of this study was to compare the diagnostic performance of DUS and MRI for the detection of MN, using concordant imaging findings, histopathologic confirmation, and clinical follow-up.

2. Materials and methods

2.1. Study design

This prospective, comparative, single-centre observational cohort study was approved by the local Institutional Ethics Committee (n. 0042416/AO/23.06.2023). Written informed consent was obtained from all participants, in accordance with the ethical standards of the Declaration of Helsinki.

Consecutive patients with clinically suspected MN were prospectively enrolled at our institution from July 2024 to June 2025. Inclusion criteria were adult patients (≥18 years) presenting with clinical suspicion of MN characterized by persistent pain localized to the second or third IMS for at least 6 months and worsening symptoms while wearing shoes.

The sample size was estimated a priori based on previously reported specificities of 88% for ultrasonography and 68% for MRI in the diagnosis of Morton's neuroma [15]. Assuming a two-sided type I error rate (α) of 0.05 and a type II error rate (β) of 0.20 (80% statistical power), the estimated minimum sample size was 67 examinations per imaging modality. As both imaging examinations were performed on each participant, a minimum of 67 evaluable lesions (MN or IMB) was required. Allowing for an anticipated 10% loss to follow-up or incomplete assessment, the target sample size was increased to at least 75 lesions.

To minimise selection bias, the following strict exclusion criteria were applied: history of recent foot trauma, joint instability and hypermobility of the first ray, intermetatarsal impingement, particularly involving the second and third metatarsals in the presence of an adducted forefoot, foot osteoarthritis, clinical evidence of active infection, prior forefoot surgery, rheumatologic disease, diabetes mellitus, peripheral neuropathy, and clinical suspicion of stress fractures or plantar plate tear. Hence, all patients underwent weight-bearing radiographs of both feet to exclude radiographic findings suggestive of any of the predefined exclusion criteria. Subsequently, all patients underwent a standardised clinical assessment performed by a senior foot and ankle orthopaedic surgeon. For patient inclusion a positive MT was required in at least one of the two suspected IMSs.

Following this clinical assessment, patients were referred to Radiology for DUS and MRI of the forefoot at our institution, performed on the same day. DUS and MRI examinations were interpreted independently by two dedicated senior musculoskeletal radiologists at our institution, each with extensive expertise in their respective imaging modality and assigned exclusively to the interpretation of that modality (DUS or MRI). Radiologists were aware of the clinical suspicion of MN and the involved IMS but were blinded to the findings of the alternative imaging modality.

In patients with bilateral clinical suspicion, imaging studies were performed on both feet, and each foot was analysed as an independent statistical unit because the objective of the study was to evaluate the diagnostic accuracy of each imaging examination for each individual foot. The potential correlation between feet from the same patient is acknowledged as a limitation.

During image interpretation, radiologists were required to classify each examined foot as either MN or IMB.

Then, all patients were referred to the same previous senior surgeon for treatment. Patients diagnosed with MN showing a maximum diameter > 5 mm in both imaging techniques (US and MRI) were offered surgical treatment, considering corticosteroid injection treatment ineffective in MN larger than 5 mm [16]. Only those who consented to surgery were retained in the study and subsequently underwent neuroma excision, while those with IMB were likewise included in the study and managed conservatively according to a standardised treatment protocol. This included: custom metatarsal pad orthoses for at list six months and anti-inflammatory therapy for two weeks (Etoricoxib 90 mg once daily; in patients with contraindications or allergy to NSAIDs, Paracetamol and Codeine phosphate, up to three times daily, was administered. Neither corticosteroid injections nor opioid analgesics were suggested as part of the diagnostic and/or treatment protocol.

The evaluated feet were classified into two groups:

- *Cases with histopathological confirmation of MN;*
- *Cases of IMB considered clinically confirmed when symptom improvement or complete resolution was observed at 12-month follow-up (NRS < 1).*

2.2. Imaging techniques

US examinations were performed using a high-resolution ultrasound system (RS85 Prestige, Samsung Medison Co., Ltd., Korea) equipped with a 2–14 MHz linear-array transducer. All examinations were performed in a standardised manner with the patient in supine position, using both a dorsal and a plantar approach (Fig. 1). For the dorsal approach, the hip was flexed at 45° and the knee at 90°, with the foot resting on the examination table to facilitate visualization of the IMS. The assessment initially focused on the IMS suspected of harbouring MN based on the clinical examination. Subsequently, a plantar approach was performed for dynamic evaluation. During this phase, the lower limb was maintained in extension with the ankle in a neutral position, allowing lateral compression of the forefoot to dynamically reproduce and assess MT.

During ultrasound examination, the following diagnostic criteria were systematically evaluated and recorded in line with the established literature [17]: lesion location, shape, margins, echotexture, maximum diameter, compressibility, Power Doppler signal, continuity with the plantar digital nerve, and the presence of MT positive (considered positive when the lesion was displaced from the IMS during forefoot compression).

MN was diagnosed on ultrasound when a well-defined, heterogeneous hypoechoic ovoid lesion was identified in the plantar aspect of the IMS near the metatarsal heads. Additional diagnostic criteria included absence of vascular signal on Power Doppler imaging, continuity with the plantar digital nerve, lack of compressibility, and a positive MT during dynamic examination. In contrast, a diagnosis of IMB was made when a compressible hypo/ anechoic lesion was detected within the IMS in the absence of a positive MT. For each lesion, the following parameters were recorded: MT, lesion

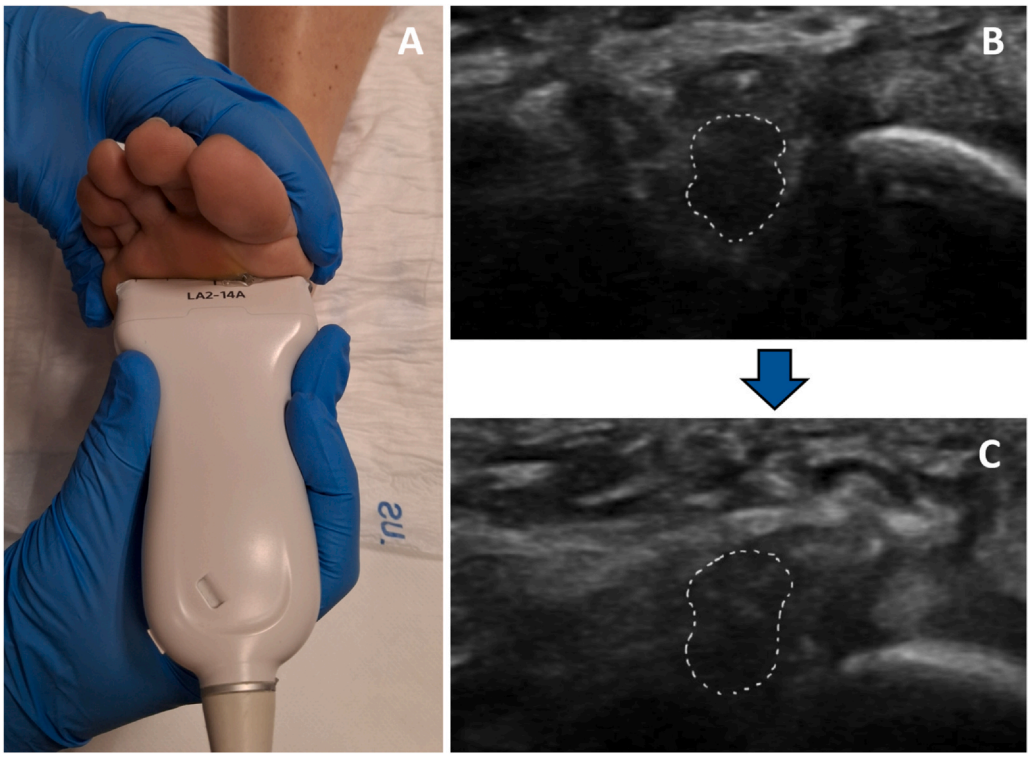

Fig. 1. Dynamic ultrasonography (DUS): Standardised examination performed with the patient in the supine position using dorsal and plantar (A) scanning approaches. Representative ultrasound image of a Morton's neuroma obtained through the dorsal approach (B). Dynamic plantar displacement of the neuroma during metatarsal compression (Mulder's test) is illustrated in (C), compared with the corresponding static image in (B).

compressibility, shape, Power Doppler signal, continuity with the nerve, and maximum lesion diameter.

MRI of the forefoot was performed using a 1.5-T scanner (Magnetom Avanto, Siemens, Erlangen, Germany) equipped with dedicated foot coils. Patients were in supine position during image acquisition. The imaging protocol followed the recommendations of the European Society of Musculoskeletal Radiology (ESSR) [18] and included sagittal sequences (T1-weighted and T2-weighted with fat suppression [STIR]), para-axial sequences oriented parallel to the long axis of the foot (T1-weighted and STIR), and para-coronal sequences oriented perpendicular to the para-axial plane (T1-weighted, T2-weighted, and STIR). The total acquisition time was approximately 20 min per foot.

On MRI, MN was diagnosed when a well-defined mass was identified in the plantar region of the IMS near the metatarsal heads, appearing hypointense on both T1- and T2-weighted sequences. In contrast, the presence of fluid signal intensity within the IMS was considered consistent with IMB (Fig. 2).

2.3. Surgery and histopathologic examination

All surgical excisions were performed by the same senior surgeon, using a dorsal approach. Patients were positioned supine, and an ankle block was administered [19]. An ankle tourniquet was applied. The procedure was performed through a 2–2.5 cm longitudinal dorsal incision centred over the involved IMS. Once the MN was identified, the distal branches of the common plantar digital nerve were transected. The deep transverse intermetatarsal ligament was then sectioned to allow adequate proximal exposure of the nerve. The nerve, together with the neuroma, was carefully dissected and transected as proximally as possible, allowing the proximal nerve stump to retract away from the weight-bearing area and thereby reducing the risk of residual pain associated with a symptomatic stump neuroma. The skin was closed using absorbable 3–0 sutures, and a sterile dressing was applied.

Excised specimens were fixed in phosphate-buffered formalin and embedded in paraffin for histopathologic evaluation. Pathologic analysis was performed using hematoxylin–eosin and trichrome staining to assess the characteristic histologic features of MN.

Postoperatively, patients were allowed to ambulate beginning on the day of discharge using a heel weight-bearing postoperative shoe. Sutures were removed at the 2-week follow-up visit.

2.4. Statistical analysis

Data are presented as percentages, medians with interquartile ranges (IQR), or means ± standard deviation (SD), as appropriate. The Kolmogorov–Smirnov test was used to assess the normality of continuous variables. For statistical analysis, examined feet were classified into two groups according to the final diagnosis: MN or IMB. Logistic regression analyses using a backward elimination approach were performed to identify which DUS and MRI features were independently associated with the diagnosis of MN.

Diagnostic performance metrics, including sensitivity, specificity, and overall accuracy, were calculated for each imaging modality in detecting MN. Positive predictive value (PPV) and negative predictive value (NPV) were also calculated.

Receiver operating characteristic (ROC) curves were generated for both DUS and MRI based on the final diagnosis of either MN or IMB. Areas under the ROC curves (AUCs) were calculated and compared using the DeLong method.

Statistical significance was defined as $P \leq .05$. All statistical analyses were performed using SPSS (version 29, IBM Corp., Armonk, NY, USA) and MedCalc (version 23.2.0, MedCalc Software Ltd., Ostend, Belgium).

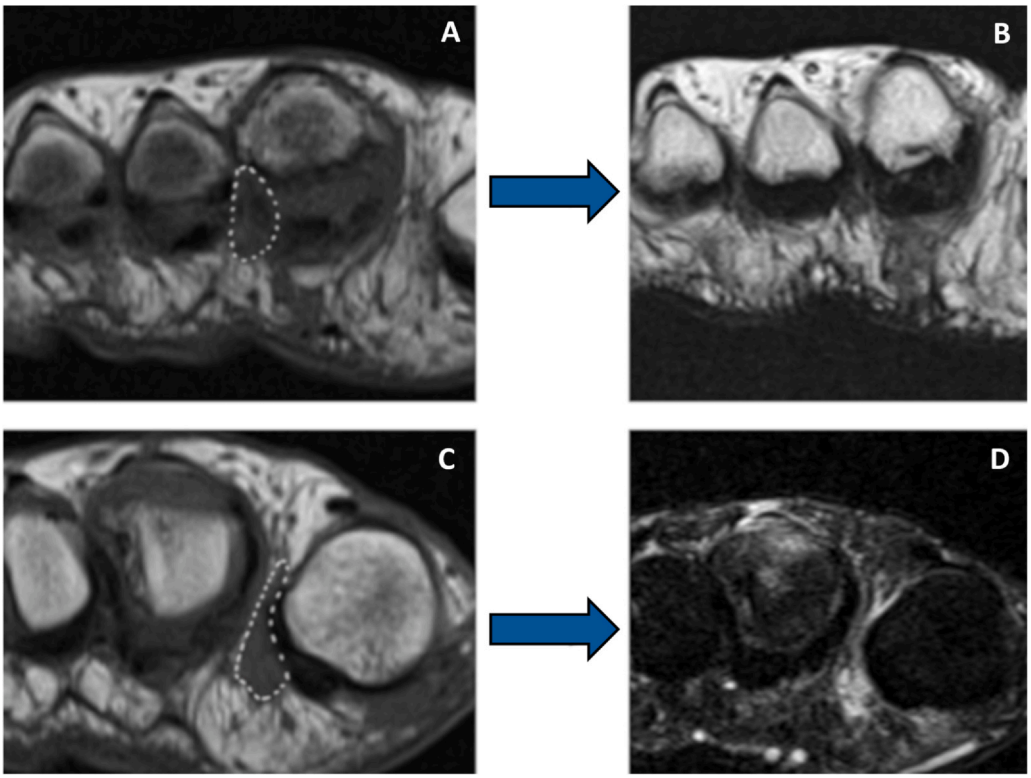

Fig. 2. MRI findings. Morton's neuroma appears hypointense on both T1-weighted (A) and T2-weighted (B) sequences. Intermetatarsal bursitis is hypointense on T1-weighted images (C) and demonstrates characteristic hyperintensity on STIR sequences (D).

3. Results

During the one-year study period, a total of 278 adult patients were evaluated at our institution for a suspected diagnosis of MN. Of these, 186 patients (66.9%) were excluded according to the predefined selection criteria, leaving 92 patients (33.1%) eligible for further assessment. Of these eligible patients, 53 (57.6%), with a median age of 58 years (range, 32–87 years), were included in the final analysis after providing informed consent, completing both DUS and MRI examinations, undergoing the surgical or conservative treatment indicated according to the study protocol, and completing the 12-month follow-up. The remaining 39 eligible patients (42.4%) were not included in the final analysis for the following reasons: 17 (43.6%) declined participation and/or did not provide informed consent; 2 (5.1%) did not complete both required imaging examinations; 12 (30.8%) did not complete the treatments specified by the study protocol; 1 (2.6%) dead before surgery and 7 (17.9%) did not complete the 12-month follow-up because they had moved away, could not be contacted, or were unavailable for clinical reassessment.

Hence, the cohort consisted of 47 women and 6 men, and a total of 76 lesions were evaluated in 76 feet: 33 right (43.4%) and 43 (56.6%) left; in 23 patients the lesions were bilateral.

Overall, 53 MNs (69.7%) and 23 IMBs (30.3%) were diagnosed. All 53 neuromas underwent surgical excision, and histopathologic confirmation was obtained in every case. However, 7 lesions showed discordant DUS and MRI findings. In 6 cases, DUS indicated MN whereas MRI indicated IMB; all 6 lesions underwent surgical excision, and histopathological examination confirmed MN (supporting the DUS diagnosis). In the remaining discordant case, MRI indicated MN whereas DUS indicated IMB. This lesion also underwent surgical excision, with histopathological examination confirming MN (supporting the MRI diagnosis).

In contrast, cases diagnosed as IMB were treated conservatively with nonsteroidal anti-inflammatory drugs (NSAIDs) and metatarsal pads, resulting in complete symptom resolution at the 12-month follow-up (NRS = 0).

The mean maximum diameter of MN was 9.5 mm on ultrasound and 8.1 mm on MRI. Ultrasound tended to slightly overestimate lesion size compared with MRI; however, this difference was not statistically significant.

Regarding anatomical distribution, 42 neuromas were in the third IMS and 11 in the second IMS.

For DUS, the following imaging features were evaluated using logistic regression analysis: MT (positive vs negative), lesion compressibility (compressible vs noncompressible), lesion shape (ovoid/rounded vs poly-lobulated), Power Doppler signal (present vs absent), continuity with the nerve (present vs absent), and maximum lesion diameter. In the final model, a positive MT (coefficient = 2.28537; P = .0015) and lesion non-compressibility (coefficient = 2.03253; P = .0027) were retained as independent predictors of MN, correctly classifying 94.59% of cases (χ^2 = 69.664; P < .001; Cox & Snell R^2 = 0.6099) (Table 1).

For MRI, the following imaging features were evaluated using logistic regression analysis: T2 signal intensity (hypointense vs hyperintense), T1 signal intensity (hypointense vs hyperintense), lesion borders (well-defined vs poorly defined), lesion location (plantar vs non-plantar), lesion shape (ovoid/rounded vs poly-lobulated), and maximum lesion diameter. In the final model, maximum lesion diameter (coefficient = 0.41102; P = .0003) and lesion shape (coefficient = 1.98910; P = .0144) were retained as independent predictors, correctly classifying 83.78% of cases (χ^2 = 29.268; P < .001; Cox & Snell R^2 = 0.3267) (Table 2).

MRI demonstrated a sensitivity of 84.91% (95% confidence interval [CI], 72.41%–93.25%), specificity of 100% (95% CI, 85.18%–100.00%), and overall accuracy of 89.47% (95% CI,

Table 1
Logistic regression analysis identifying independent predictors.

Modality	Variables	Coefficient	Accuracy	X^2 (p-value)	Cox & Snell R^2
DUS	Positive MS	2.285	94.59%	69.664	0.6099
	Non compressibility	2.032		(p < .001)	
MRI	Maximum diameter	0.411	83.78%	29.268	0.3267
	Shape	1.989		(p < .001)	

Table 2
Ultrasound features and diagnostic indicators for Morton's neuroma (MN) and intermetatarsal bursitis (IMB).

Parameter	Morton's neuroma	IMB
Shape	Ovoid / solid	Irregular / fluid-filled
Echotexture	Heterogeneously hypoechoic	Hypo- or anechoic
Compressibility	Absent	Present
Mulder's sign	Positive	Negative
Power Doppler	Absent	Occasionally present
Continuity with the nerve	Present	Absent

Table 3
Comparative analysis of the diagnostic performance of dynamic ultrasonography (DUS) and magnetic resonance imaging (MRI).

Parameter	DUS	MRI
Sensitivity (%)	**98.11**	84.91
Specificity (%)	**100**	**100**
Accuracy (%)	**98.68**	89.47
Positive Predictive Value (%)	**100**	**100**
Negative Predictive Value (%)	**95.83**	74.19
AUC	**0.991**	0.925

80.31%–95.34%). The positive predictive value (PPV) was 100% (95% CI, 92.13%–100%), and the negative predictive value (NPV) was 74.19% (95% CI, 60.29%–84.48%) (Table 3).

DUS demonstrated a sensitivity of 98.11% (95% CI, 89.93%–99.95%), specificity of 100% (95% CI, 85.18%–100%), and overall accuracy of 98.68% (95% CI, 92.89%–99.97%). The PPV was 100% (95% CI, 93.15%–100%), and the NPV was 95.83% (95% CI, 76.75%–99.38%).

Notably, in seven cases were correctly identified as MN by DUS but were misdiagnosed as IMB by MRI.

The area under the receiver operating characteristic curve (AUC) was 0.991 (95% CI, 0.935–1.000) for ultrasound and 0.925 (95% CI, 0.841–0.973) for MRI. The difference between the AUCs of the two techniques was statistically significant (difference = 0.0660; 95% CI, 0.0130–0.119; P = .0147), indicating higher diagnostic accuracy for DUS.

4. Discussion

The diagnosis of Morton syndrome is primarily clinical [8,10]. Accurate IMS identification is crucial, as Levitsky [19] reported, neuromas may occur in adjacent spaces in up to 28% of cases compared with the clinically suspected location. However, several authors have emphasized that clinical evaluation alone may be insufficient, and imaging studies confirm the diagnosis [9,20].

Conventional radiography does not allow direct visualization of MN [11,21]. Recently, Galley [22] described the Vulcan salute radiographic sign (V-sign), with high specificity but limited sensitivity for MN. High-resolution US, MRI, with or without contrast enhancement, and even computed tomography have been used to support the diagnosis [23–27]. Currently US and MRI are the main modalities for IMS identification; ultrasound has been recognized as highly accurate for MN since the 1980s [28–30].

In our study, DUS demonstrated excellent diagnostic performance, proving significantly superior to MRI in terms of AUC. The most predictive sonographic parameters were a positive MT and lesion non-compressibility. Consistent with Sobiesk [30], ultrasound accurately detects MN presence, location, and size. Fenech highlighted ultrasound's superior dynamic assessment, [31] while Reijnierse and Griffith confirmed it as first-line imaging for forefoot disorders [32]. Similarly, Perini et al. [33] supported dynamic ultrasonography as the first-line imaging modality to confirm clinical findings and identify the location and number of MN lesions, while emphasising the role of MRI in the differential diagnosis of other forefoot disorders (mainly stress fractures, bursitis, ganglion cysts or tendon tumour sheaths).

In our cohort, MRI showed 84.9% sensitivity and 74.2% NPV, with more false negatives than ultrasound; similarly reported by Fazal [12] and Torres-Claramunt [13], particularly when differentiating MN from IMB.

Zanetti [34] reported 89% sensitivity and 100% specificity; contrast-enhanced MRI may improve image quality but remains limited for small lesions, so it was not used in the present study [26]. Similarly, Fazal [12] showed US detects neuromas < 5 mm better than MRI, which may yield false negatives.

Previous studies have suggested that approximately 5 mm may represent the threshold above which a neuroma becomes more likely to produce clinical symptoms [29]. In this study the mean maximum diameter of MN measured 9.5 mm on ultrasound and 8.1 mm on MRI. Ultrasound tended to slightly overestimate lesion size compared with MRI; however, this difference was not statistically significant.

Biasca [35] noted MRI may aid preoperative localization in selected cases, but with lower clinical concordance; Classen [36] also found it may be less accurate than clinical examination.

Resch [25] reported relatively low sensitivity for both imaging modalities, although their study was limited by a small sample size. Sharp [37] suggested that imaging may be unnecessary when clinical findings are highly suggestive; however, this assumption has been challenged by more recent studies.

The systematic reviews by Bignotti et al. [14] and Xu et al. [15] reported comparable diagnostic performance of ultrasound and MRI for Morton's neuroma, supporting ultrasound as the preferred first-line imaging modality because of its lower cost, wider availability, and ability to provide dynamic assessment. IMB may mimic MN both clinically and radiologically [38] and lead to overdiagnosis. Lachhab [39] reported several cases of bursitis initially misdiagnosed as neuromas. However, in our study DUS reliably distinguishes between them.

In this study DUS showed excellent diagnostic performance and may be considered a reference imaging modality rather than secondary. Performed by experienced radiologists, ultrasound offers high accuracy and greater cost-effectiveness than MRI (€60 vs €145 according to reimbursement rates within our National Health Service).

Several limitations should be acknowledged:

- this study was conducted at a single centre with a relatively limited sample size, though adequately powered and comparable to prior studies;

- in the statistical analysis, 76 lesions were analysed independently despite clustering within 53 patients, therefore, shared biomechanical factors affecting both feet, potentially contributing to the development of neuroma or bursitis, cannot be excluded. Further, tertiary-centre recruitment may overestimate neuroma prevalence;
- a further limitation is the potential for selection and attrition bias, as 39 of the 92 eligible patients were not included in the final analysis because of refusal to participate, incomplete imaging or treatment, or loss to follow-up. Since complete diagnostic and follow-up data were not available for these patients, we cannot exclude the possibility that their lesion characteristics or diagnostic findings differed from those of the analysed cohort. This may have influenced the diagnostic performance estimates and should be considered when interpreting our findings;
- a potential bias relates to the blinding protocol: ultrasound was dynamic and clinically guided, whereas MRI was static, potentially favouring ultrasound, although this reflects routine clinical practice;
- the study did not assess inter- or intra-observer agreement because image interpretation was performed by one dedicated senior musculoskeletal radiologist for each imaging modality. The primary aim was to evaluate diagnostic accuracy under routine clinical practice conditions rather than observer reproducibility;
- histology confirmed only MNs, providing a robust reference standard, whereas IMBs relied on clinical follow-up in accordance with current guidelines [38].

Despite these limitations, the present study has several important methodological strengths:

- Prospective design with DUS and MRI performed on the same day, independently interpreted by experienced musculoskeletal radiologists, minimizing bias.
- The dynamic nature of ultrasound allows real-time assessment of compressibility and MT, directly correlating imaging with symptoms
- ROC analysis further confirmed the robustness of our findings. The near-perfect AUC observed for ultrasound suggests an outstanding ability of ultrasound to discriminate between the presence and absence of MN. From a statistical perspective, these results strengthen the internal validity of the study and support the reliability of the diagnostic estimates obtained.

Nevertheless, future prospective multicentre studies incorporating multiple readers, formal inter- and intra-observer agreement analyses, standardised imaging protocols, and surgical–histopathological correlation would further strengthen the generalisability of these findings and support more informed clinical decision-making in patients with forefoot pain.

5. Conclusions

DUS demonstrated superior diagnostic performance compared with MRI in the preoperative evaluation of MN, with higher sensitivity, negative predictive value, overall diagnostic accuracy and more cost-effectiveness.

Considering its higher cost and longer acquisition time, MRI should be reserved for cases with inconclusive ultrasound findings, when a more detailed anatomical evaluation is required, or when alternative causes of forefoot pain are suspected.

Our findings support the use of DUS as the preferred first-line imaging modality in the diagnosis of MN, which may streamline clinical pathways, reduce healthcare costs, and improve patient selection for surgery.

CRediT authorship contribution statement

Carlo Biz: Conceptualization, Validation, Resources, Writing-original draft preparation, review & editing, Supervision, Project administration. **Filippo Crimì:** Methodology, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization. **Giovanni Sciarretta:** Investigation, Writing-original draft preparation, Writing – review & editing, Visualization. **Alberto Crimì:** Investigation, Writing-original draft preparation, Writing – review & editing. **Antonella Dimaggio**: Investigation, Data curation, Writing-original draft preparation, Visualization. **Antonio Corso**: Investigation, Data curation. **Raimondo Angelone:** Investigation, Data curation. **Emilio Quaia:** Resources, Supervision. **Pietro Ruggieri:** Resources, Supervision.

Ethics declaration

Written informed consent to take part in the study and to publish the article has been obtained from all participants or their legal representatives. The privacy rights of participants have been observed.

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place. This study was approved by the Ethics committee of Padua Hospital. (Approval No. n. 0042416/AO/23.06.2023).

Ethical approval

This study was performed in accordance with the ethical standards of the institutional and/or national research committee, the 1964 Declaration of Helsinki and its later amendments, or comparable ethical standards. The Institutional Ethics Committee approved this study on 23 June 2023 (n. 0042416/AO/23.).

Consent to participate and for publication

The patients gave their written informed consent to participate in the study and for the publication of their anonymous and clustered data and anonymous pictures.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Data availability

The datasets generated and analysed in the current study are not publicly available due to data protection regulations. Access to data is limited to the researchers who have obtained permission for data processing. Further inquiries can be made to the corresponding author.

Declaration of Competing Interest

None.

Acknowledgements

None.

References

[1] Pisani G. Is it Morton's or Civinini's syndrome? Foot Ankle Surg 2010;16(3):105–6. https://doi.org/10.1016/j.fas.2009.07.006
[2] Biz C, Bonvicini B, Sciarretta G, Pendin M, Cecchetto G, Ruggieri P. Digital ischemia after ultrasound-guided alcohol injection for Morton's syndrome: case report and review of the literature. J Clin Med 2022;11(21):6263. https://doi.org/10.3390/jcm11216263

[3] Wu KK. Morton's interdigital neuroma: a clinical review of its etiology, treatment, and results. J Foot Ankle Surg 1996;35(2):112–9. https://doi.org/10.1016/s1067-2516(96)80027-5
[4] Giannini S, Bacchini P, Ceccarelli F, Vannini F. Interdigital neuroma: clinical examination and histopathologic results in 63 cases treated with excision. Foot Ankle Int 2004;25(2):79–84. https://doi.org/10.1177/107110070402500208
[5] Biz C, Crimì A, Mori F, Zinnarello DF, Sciarretta G, Ruggieri P. Morton's neuroma: who, when and how contributed to its description and treatment? Int Orthop 2025;49(4):975–87. https://doi.org/10.1007/s00264-024-06390-3
[6] Hassouna H, Singh D. Morton's metatarsalgia: pathogenesis, aetiology and current management. Acta Orthop Belg 2005;71(6):646–55.
[7] Stecco C, Fantoni I, Macchi V, Del Borrello M, Porzionato A, Biz C, De Caro R. The role of fasciae in Civinini-Morton's syndrome. J Anat 2015;227(5):654–64. https://doi.org/10.1111/joa.12371
[8] Dando C, Cherry L, Jones L, Bowen C. The clinical diagnosis of symptomatic forefoot neuroma in the general population: a Delphi consensus study. J Foot Ankle Res 2017;10(1):59. https://doi.org/10.1186/s13047-017-0241-2
[9] Jain S, Mannan K. The diagnosis and management of Morton's neuroma: a literature review. Foot Ankle Spec 2013;6(4):307–17. https://doi.org/10.1177/1938640013493464
[10] Pitcher M, Moulson A, Pitcher D, Herbland A, Cert G, Cairns MC. Diagnostic accuracy of subjective features and physical examination tests for Morton neuroma: a systematic review. Foot Ankle Orthop 2024;9(4):24730114241291055. https://doi.org/10.1177/24730114241291055
[11] Afonso PD, Britto SV, Spritzer CE, Martins e Souza P. Differential diagnosis of metatarsalgia. Semin Musculoskelet Radiol 2023;27(3):337–50. https://doi.org/10.1055/s-0043-1764388
[12] Fazal MA, Khan I, Thomas C. Ultrasonography and magnetic resonance imaging in the diagnosis of Morton's neuroma. J Am Podiatr Med Assoc 2012;102(3):184–6. https://doi.org/10.7547/1020184
[13] Torres-Claramunt R, Ginés A, Pidemunt G, Puig L, de Zabala S. Indian J Orthop 2012;46(3):321–5. https://doi.org/10.4103/0019-5413.96390
[14] Bignotti B, Signori A, Sormani MP, Molfetta L, Martinoli C, Tagliafico A. Ultrasound versus magnetic resonance imaging for Morton neuroma: systematic review and meta-analysis. Eur Radiol 2015;25(8):2254–62. https://doi.org/10.1007/s00330-015-3633-3
[15] Xu Z, Duan X, Yu X, Wang H, Dong X, Xiang Z. The accuracy of ultrasonography and magnetic resonance imaging for the diagnosis of Morton's neuroma: a systematic review. Clin Radiol 2015;70(4):351–8. https://doi.org/10.1016/j.crad.2014.10.017
[16] Makki D, Haddad BZ, Mahmood Z, Shahid MS, Pathak S, Garnham I. Efficacy of corticosteroid injection versus size of plantar interdigital neuroma. Foot Ankle Int 2012;33(9):722–6. https://doi.org/10.3113/FAI.2012.0722
[17] Quinn TJ, Jacobson JA, Craig JG, van Holsbeeck MT. Sonography of Morton's neuromas. AJR Am J Roentgenol 2000;174(6):1723–8. https://doi.org/10.2214/ajr.174.6.1741723. PMID: 10845513.
[18] European Society of Skeletal Radiology (ESSR) Sports Sub-committee. Foot (Mid- and Forefoot) MRI Protocol. MRI Protocols for ESSR: Guidelines for MR Imaging of Sports Injuries. https://www.essr.org/content-essr/uploads/2016/10/ESSR-MRI-Protocols-Foot.pdf; 2016.
[19] Biz C, de Iudicibus G, Belluzzi E, Dalmau-Pastor M, Bragazzi NL, Funes M, Parise GM, Ruggieri P. Prevalence of chronic pain syndrome after hallux valgus percutaneous surgery. BMC Musculoskelet Disord 2021;22(1):1043. https://doi.org/10.1186/s12891-021-04911-4
[20] Gougoulias N, Lampridis V, Sakellariou A. Morton's interdigital neuroma: instructional review. EFORT Open Rev 2019;4(1):14–24. https://doi.org/10.1302/2058-5241.4.180025
[21] Gregg J, Marks P. Metatarsalgia: an ultrasound perspective. Australas Radiol 2007;51(6):493–9. https://doi.org/10.1111/j.1440-1673.2007.01886.x
[22] Galley J, Sutter R, Germann C, Pfirrmann CWA. The Vulcan salute sign: a non-sensitive but specific sign for Morton's neuroma on radiographs. Skelet Radiol 2022;51(3):581–6. https://doi.org/10.1007/s00256-021-03851-3
[23] Levine SE, Myerson MS, Shapiro PP, Shapiro SL. Ultrasonographic diagnosis of recurrence after excision of an interdigital neuroma. Foot Ankle Int 1998;19(2):79–84. https://doi.org/10.1177/107110079801900205
[24] Pollak RA, Bellacosa RA, Dornbluth NC, Strash WW, Devall JM. Sonographic analysis of Morton's neuroma. J Foot Surg 1992;31(6):534–7.
[25] Resch S, Stenstrom A, Jonsson A, Jonsson K. The diagnostic efficacy of magnetic resonance imaging and ultrasonography in Morton's neuroma: a radiological-surgical correlation. Foot Ankle Int 1994;15(2):88–92. https://doi.org/10.1177/107110079401500208
[26] Terk MR, Kwong PK, Suthar M, Horvath BC, Colletti PM. Morton neuroma: evaluation with MR imaging performed with contrast enhancement and fat suppression. Radiology 1993;189(1):239–41. https://doi.org/10.1148/radiology.189.1.8372200
[27] Turan I, Lindgren U, Sahlstedt T. Computed tomography for diagnosis of Morton's neuroma. J Foot Surg 1991;30(3):244–5.
[28] Redd RA, Peters VJ, Emery SF, Branch HM, Rifkin MD. Morton neuroma: sonographic evaluation. Radiology 1989;171(2):415–7. https://doi.org/10.1148/radiology.171.2.2649918
[29] Shapiro PP, Shapiro SL. Sonographic evaluation of interdigital neuromas. Foot Ankle Int 1995;16(10):604–6. https://doi.org/10.1177/107110079501601003
[30] Sobiesk GA, Wertheimer SJ, Schulz R, Dalfovo M. Sonographic evaluation of interdigital neuromas. J Foot Ankle Surg 1997;36(5):364–6. https://doi.org/10.1016/s1067-2516(97)80038-5
[31] Fenech M. Sonographic anatomy and technique to image the plantar digital nerves and aid identification of a Morton's neuroma. Ultrasound 2024;32(2):114–26. https://doi.org/10.1177/1742271X231215716
[32] Reijnierse M, Griffith JF. High-resolution ultrasound and MRI in the evaluation of the forefoot and midfoot. J Ultrason 2023;23(95):e251–60. https://doi.org/10.15557/jou.2023.0033
[33] Perini L, Del Borrello M, Cipriano R, Cavallo A, Volpe A. Dynamic sonography of the forefoot in Morton's syndrome: correlation with magnetic resonance and surgery. Radiol Med 2006;111(7):897–905. https://doi.org/10.1007/s11547-006-0088-2
[34] Zanetti M, Strehle JK, Kundert HP, Zollinger H, Hodler J. Efficacy of MR imaging in patients suspected of having Morton's neuroma. AJR Am J Roentgenol 1997;168(2):529–32. https://doi.org/10.2214/ajr.168.2.9016241
[35] Biasca N, Zanetti M, Zollinger H. Outcomes after partial neurectomy of Morton's neuroma related to preoperative case histories, clinical findings, and MRI findings. Foot Ankle Int 1999;20(9):568–75. https://doi.org/10.1177/107110079902000906
[36] Claassen L, Bock K, Ettinger M, Waizy H. Role of MRI in detection of Morton's neuroma. Foot Ankle Int 2014;35(10):1002–5. https://doi.org/10.1177/1071100714540888
[37] Sharp RJ, Wade CM, Hennessy MS, Saxby TS. The role of MRI and ultrasound imaging in Morton's neuroma and the effect of size of lesion on symptoms. J Bone Jt Surg Br 2003;85(7):999–1005. https://doi.org/10.1302/0301-620x.85b7.12633
[38] Larsen SB, Søgaard SB, Nielsen MB, Torp-Pedersen ST. Diagnostic considerations of intermetatarsal bursitis: a systematic review. Diagnostics 2023;13(2):211. https://doi.org/10.3390/diagnostics13020211
[39] Lachhab A, Benghali Y, Maroc M, Nkhili Y, El Oumri AA. Ultrasound-guided diagnosis of intermetatarsal bursitis mimicking Morton's neuroma: a case report. Cureus 2025;17(2):e86184. https://doi.org/10.7759/cureus.86184