DOI: https://doi.org/10.30841/2786-7323.4.2025.350464

Sonographic assessment of painful stumps: identifying diagnostic patterns of residual limb pain after amputation

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Residual limb pain (RLP) is a common disabling complication of amputation. RLP etiologies are multifactorial, including neuromas, heterotopic ossification (HO), infection, scar tissue, and prosthesis-related complications. While magnetic resonance imaging and computed tomography are useful, ultrasound (US) is uniquely accessible, dynamic, and cost-effective for bedside evaluation. We selected US for screening RLP because it provides high-sensitivity, high-specificity bedside visualization of superficial and peristump/periprosthetic pain generators (neuroma, bursitis/seroma/hematoma, scar-related pathology/abscess, foreign bodies), allows Doppler assessment of perfusion and venous thrombosis plus dynamic "sonopalpation" and guidance of minimally invasive interventions, and does so without ionizing radiation – making US the optimal first-line test in the diagnostic workup of RLP.

***The objective:* to identify sonographic diagnostic patterns associated with RLP and evaluate their correlation with clinical presentation.**

***Materials and methods.* A prospective observational study included 237 patients following amputation (6–24 months post-amputation) with painful stumps. Clinical evaluation and standardized US were performed using high-frequency linear transducers (10–18 MHz). Sonographic features of neuromas, HO, infection/osteomyelitis, scar contracture, and prosthesis-related complications were documented. Frequencies and clinical correlations were analyzed.**

***Results.* Neuromas were detected in 18% of cases, typically as hypoechoic oval lesions continuous with a transected nerve, reproducing pain with probe pressure (Tinel sign). HO was present in 13%, visualized as hyperechoic masses with acoustic shadowing. Infection/abscesses occurred in 12%, appearing as hypoechoic fluid collections with peripheral hypervascularity on Doppler. Scar tethering was identified in 22%, with reduced tissue glide and hyperechoic fibrotic bands. Prosthesis-related complications (bursitis, hematomas, soft tissue edema) were observed in 18%. Clinical correlation confirmed high concordance between ultrasound findings and pain localization.**

***Conclusions.* Ultrasound reliably identifies structural causes of RLP, with characteristic patterns for neuromas, HO, infection, and soft tissue pathology. Given its accessibility and dynamic assessment capabilities, US should be considered a first-line imaging modality for evaluating painful amputation stumps.**

Keywords: *residual limb pain, ultrasound, neuroma, heterotopic ossification, prosthesis-related complications.*

Сонографічне оцінювання болючих кукс: діагностичні патерни резидуального болю кінцівки після ампутації

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Біль у куксі (БК) – поширене та інвалідизуюче ускладнення після ампутації. Етіологія БК є мультифакторною і включає невроми, гетеротопічну осифікацію (ГО), інфекцію, рубцеву тканину та ускладнення, пов'язані з протезом. Хоча магнітно-резонансна і комп'ютерна томографія інформативні, ультразвукове дослідження (УЗД) є унікально доступним, динамічним та економічно вигідним методом біля ліжка пацієнта. Ми обрали УЗД для скринінгу БК, оскільки воно забезпечує високу чутливість і специфічність при візуалізації поверхневих та навколокуксових/навколопротезних джерел болю (неврома, бурсит/серома/гематома, рубцева патологія/абсцес, сторонні тіла), дозволяє проводити допплерівське оцінювання перфузії й венозного тромбозу, застосовувати динамічну сонопальпацію та виконувати наведені малоінвазивні втручання – і все це без іонізувального випромінювання, що робить УЗД оптимальним методом першої лінії в діагностичному алгоритмі БК.

Мета дослідження: виявити сонографічні діагностичні патерни, пов'язані з БК, та оцінити їх кореляцію з клінічною картиною.

Матеріали та методи. Проспективне спостережне дослідження включило 237 пацієнтів після ампутації (6–24 міс. після ампутації) з болючими куксами. Проведено клінічне оцінювання та стандартизовані УЗД з використанням високочастотних лінійних датчиків (10–18 МГц). Документували сонографічні ознаки невром, ГО, інфекції/остеомієліту, рубцевої контрактури та ускладнень, пов'язаних із протезом. Проаналізовано частоти знахідок і їх клінічні кореляції.

Результати. Невроми виявлено у 18% випадків, зазвичай як гіпоехогенні овальні утворення, безперервні з перерізаним нервом, із відтворенням болю під тиском датчика (симптом Тінеля). ГО виявлено у 13% випадків; вона візуалізувалась у вигляді гіперехогенних мас з акустичною тінню. Інфекція/абсцеси – у 12% випадків; вони візуалізувались як гіпоехогенні рідинні скупчення з периферичною гіперваскуляризацією за даними допплерівського дослідження. Рубцеве «підтягування» (tethering) і знижене ковзання тканин відзначено у 22% випадків із гіперехогенними фіброзними смугами. Ускладнення, пов'язані з протезом (бурсит, гематоми, набряк м'яких тканин), спостерігали у 18% випадків. Клінічна кореляція підтвердила високу відповідність між ультразвуковими знахідками та локалізацією болю.

Висновки. Ультразвук надійно ідентифікує структурні причини БК з характерними патернами для невром, ГО, інфекції та патології м'яких тканин. Завдяки доступності й можливості динамічного оцінювання, УЗД слід вважати методом першої лінії під час обстеження болючих кукс після ампутації.
Ключові слова: *резидуальний біль кінцівки, ультразвукове дослідження, неврома, гетеротопічна осифікація, протез-асоційовані ускладнення.*

Residual limb pain (RLP) after amputation is a highly prevalent and disabling condition, reported in up to 80% of amputees across both civilian and military populations. It represents a heterogeneous syndrome with multifactorial origins, encompassing neuropathic mechanisms such as neuroma formation, nerve entrapment, and complex regional pain, as well as nociceptive drivers including heterotopic ossification (HO), bursitis, soft-tissue inflammation, and prosthetic interface complications. Importantly, neuropathic and nociceptive processes often coexist within the same individual, leading to diagnostic uncertainty and suboptimal treatment outcomes [2]. Accurate identification of the underlying etiology is therefore critical for targeted pain management, optimization of prosthetic fitting, and restoration of function and quality of life [3]. Advanced imaging modalities such as magnetic resonance imaging (MRI) and computer tomography (CT) are traditionally employed to evaluate structural and pathological changes within the residual limb [3–7]. However, these techniques are costly, limited in availability, and impractical for routine use in rehabilitation clinics. Moreover, MRI and CT provide static images that do not adequately capture dynamic interactions between the residual limb and prosthetic socket or reproduce pain symptoms during movement [8–11].

High-resolution ultrasound (US) has become a versatile, accessible, and cost-effective imaging modality for amputees, offering bedside use in both rehabilitation and outpatient prosthetic settings. It provides dynamic, real-time visualization of nerves, muscles, scar tissue, vessels, and bone surfaces while safely avoiding radiation, contrast exposure, and high costs [3, 11–14]. These features make US particularly suited to the needs of post-amputation populations, where frequent assessments and functional integration with rehabilitation programs are essential. In addition, real-time correlation between imaging findings and clinical symptoms allows for a more precise mapping of pain generators, guiding both interventional procedures (e.g., targeted nerve blocks, steroid injections) and surgical decision-making (e.g., neuroma excision, revision surgery) [15–18]. Despite its increasing use, systematic studies describing the sonographic spectrum of RLP remain limited. Most available data derive from small case series or anecdotal reports, lacking standardized protocols for image acquisition and interpretation. A clearer understanding of typical sonographic patterns – including neuroma, HO, bone spurs, infection, and soft-tissue edema – is necessary to establish US as a reliable diagnostic tool in this patient population [19–22].

The present study therefore aimed to characterize US features associated with common causes of RLP, to classify their diagnostic patterns, and to correlate these findings with clinical presentation during the late rehabilitation phase after amputation. By defining reproducible sonographic criteria, we seek to provide clinicians with a practical diagnostic framework for evaluating stump pain and guiding individualized treatment strategies.

MATERIALS AND METHODS

This was a prospective observational study conducted between January 2023 and December 2025 at the Superhumans Center for War Trauma Rehabilitation (Lviv, Ukraine), a tertiary referral facility dedicated to the management and rehabilitation of military personnel with complex limb injuries.

All participants provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki and applicable Ukrainian regulations. The observational registry was registered in "Ukrainian Institute of Scientific and Technical Expertise and Information" No. 0125U003136. A total of 237 adult patients (≥ 18 years) with unilateral or bilateral upper- or lower-limb amputation were consecutively enrolled. Eligible patients had undergone amputation 6–24 months prior to recruitment and presented with persistent RLP.

Exclusion criteria were defined as follows: phantom limb pain without concomitant localized stump pain, incomplete or technically inadequate US, stump revision surgery performed within the preceding 3 months, patients with multiple amputations.

A standardized clinical evaluation protocol was applied. Pain intensity was quantified using the 11-point Numeric Rating Scale (0–10). Pain descriptors (burning, stabbing, throbbing, pressure-like) were systematically collected using the Douleur Neuropathique en 4 questions framework, adapted for RLP. Potential aggravating and alleviating factors, including prosthetic wear, mechanical load, and palpation, were documented in a structured case report form (Table 1).

All US were performed by experienced musculoskeletal sonographers (minimum 5 years of expertise) using high-frequency linear-array transducers (10–18 MHz; GE Logiq and Philips Epiq systems). The scanning protocol was based on the European Federation of Societies for Ultrasound in Medicine and Biology guidelines for musculoskeletal applications.

Table 1

Demographic and clinical characteristics of the study population (n = 237)

Characteristics	Values
Age, years (M ± SD)	34.8 ± 7.5
Age range, years	19–58
Sex, n (%)	
• Male	213 (89.9)
• Female	24 (10.1)
Level of amputation, n (%)	
• Lower limb (transfemoral)	112 (47.3)
• Lower limb (transtibial)	78 (32.9)
• Upper limb (transhumeral)	31 (13.1)
• Upper limb (transradial)	16 (6.7)
Time since amputation, months (M ± SD)	13.4 ± 5.2
Range, months	6–24

Note: values are presented as mean (M) ± standard deviation (SD) for continuous variables and as absolute numbers (percentages) for categorical variables.

The following anatomical structures were systematically evaluated: peripheral nerve stumps, surrounding soft tissues (muscle, fascia, subcutaneous tissue), bone–soft tissue interface, areas of scarring or suspected tethering.

Dynamic maneuvers were incorporated, including probe compression, passive and active limb motion to assess gliding and tethering, and simulation of prosthetic application to reproduce mechanical stress. Color and power Doppler were employed when infection or hyperemia was suspected.

Predefined diagnostic criteria were applied according to current musculoskeletal ultrasound standards:

- **neuroma:** hypoechoic, ovoid swelling at the terminal portion of a transected nerve, continuous with the parent nerve, eliciting pain under probe pressure (positive sonographic Tinel sign);
- **HO:** hyperechoic foci with posterior acoustic shadowing and irregular cortical margins, distinct from the native bone edge;
- **infection/abscess:** hypoechoic or complex fluid collection with ill-defined borders, increased peripheral vascularity on Doppler, and clinical correlation with erythema or systemic signs;
- **scar tethering:** hyperechoic fibrotic bands traversing fascial planes, associated with restricted gliding during dynamic assessment;
- **prosthesis-related lesions:** localized bursal hypertrophy, hematomas, soft-tissue edema, or cutaneous/subcutaneous changes in pressure-bearing regions.

Data was entered into a secure database and analyzed using SPSS version 27.0 (IBM Corp., Armonk, NY). Continuous variables were summarized as means ± standard deviation (SD), while categorical variables were expressed as absolute frequencies and percentages. The prevalence of each sonographic abnormality was calculated. Concordance between sonographic features and clinical pain descriptors was analyzed descriptively.

RESULTS AND DISCUSSION

A total of 237 patients were included in the study. The mean age of the cohort was 34.8 ± 7.5 years (range 19–58 years). The vast majority were male (89.9%), with female patients accounting for 10.1%. Most amputations involved the lower limbs (80.2%), comprising transfemoral (47.3%) and transtibial (32.9%) levels, while upper limb amputations represented 19.8% (transhumeral 13.1%, transradial 6.7%). The mean time since amputation at the time of enrollment was 13.4 ± 5.2 months (range 6–24 months), consistent with the late rehabilitation period under investigation.

Examples of sonographic findings (Fig. 1–5).

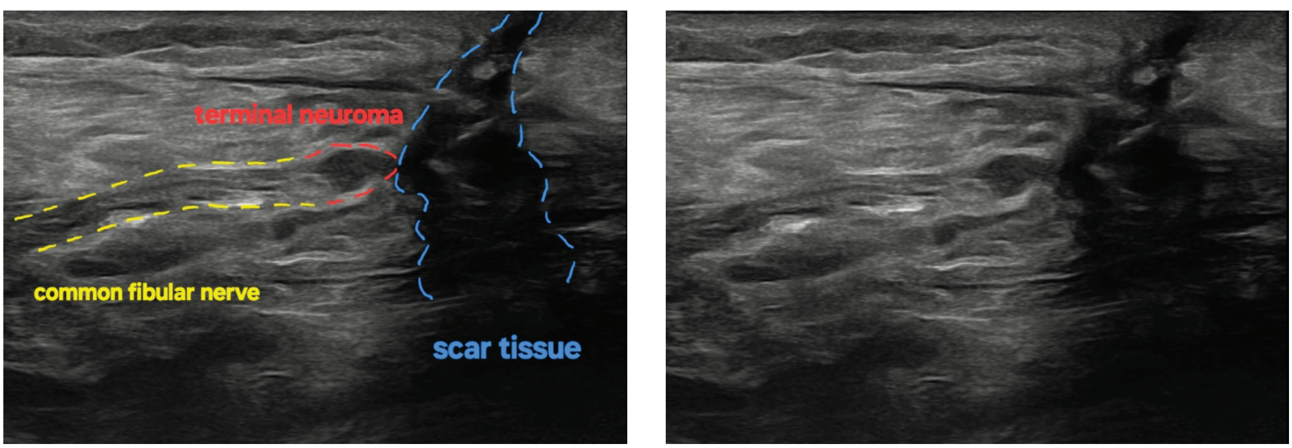

Fig. 1 (marked and non-marked). Terminal painful neuroma of the common fibular nerve with scar tissue entrapment (patient with transtibial amputation) (long axis of the nerve)

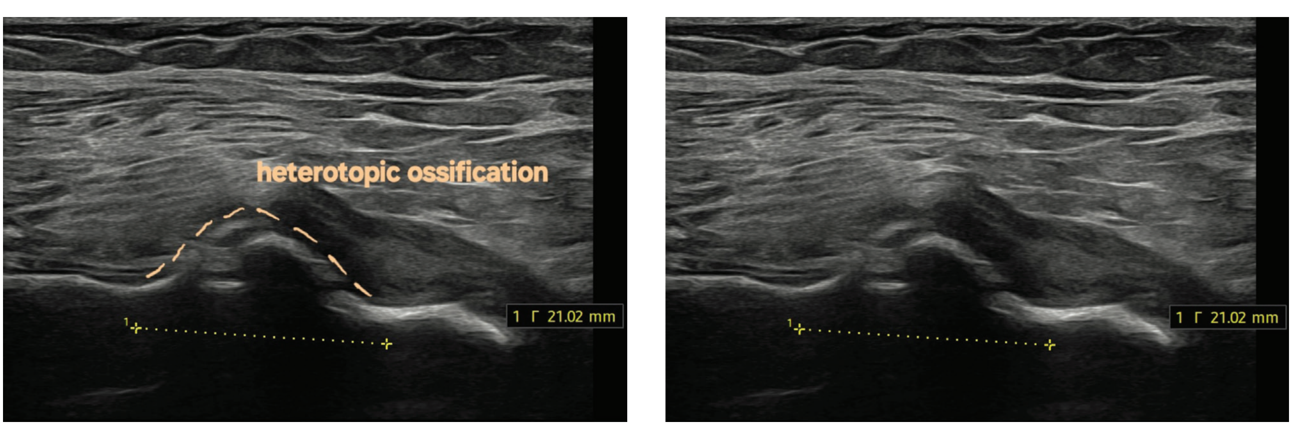

Fig. 2 (marked and non-marked). HO of the posterior surface of the femur (patient with transfemoral amputation) (long axis of the bone)

Note: HO – heterotopic ossification.

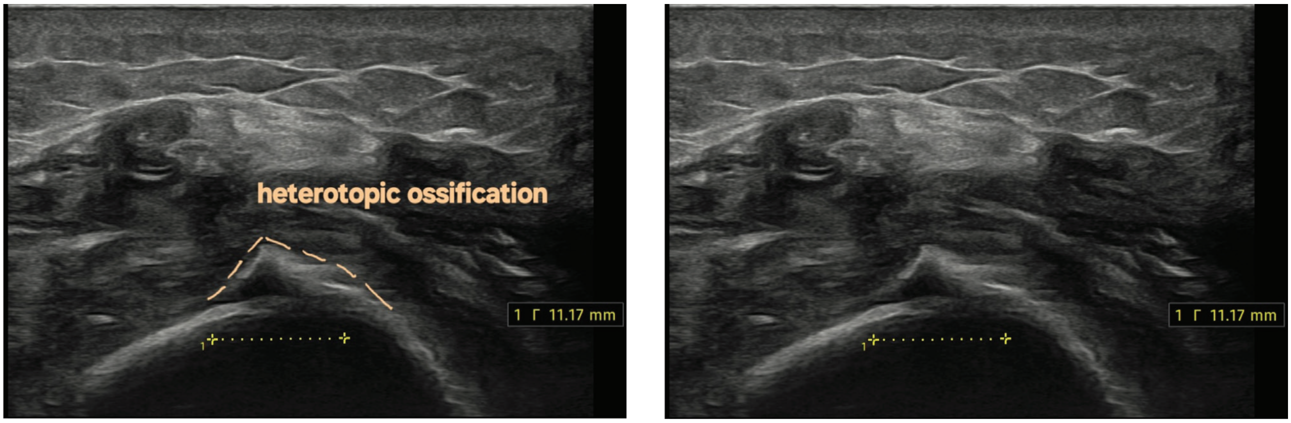

Fig. 3 (marked and non-marked). HO of the posterior surface of the fibula (patient with transtibial amputation) (short axis of the bone)

Note: HO – heterotopic ossification.

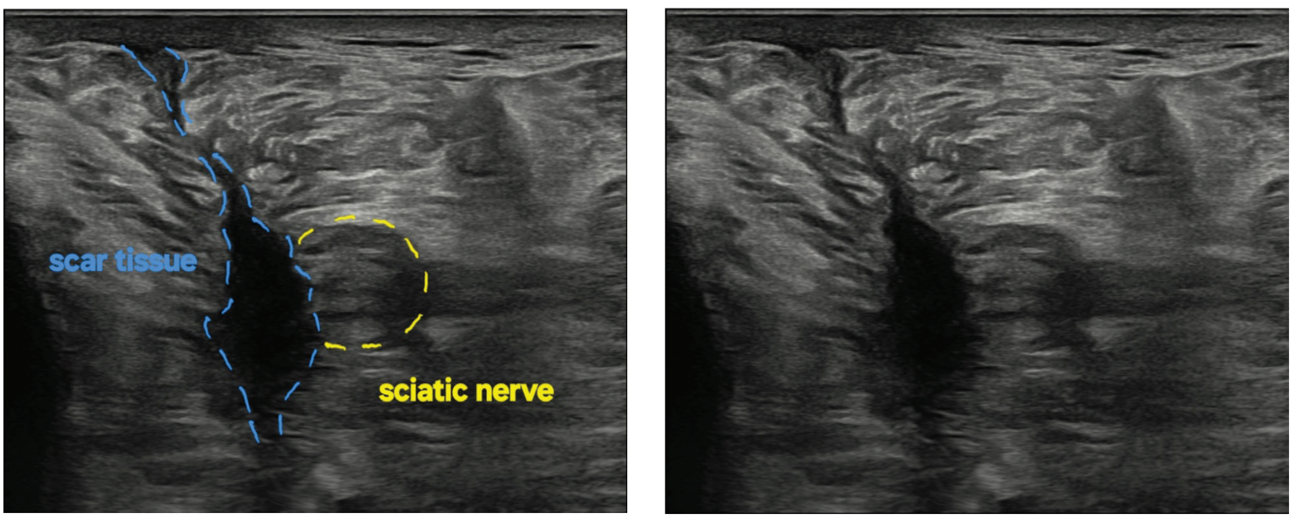

Fig. 4 (marked and non-marked). Scar tissue entrapment of the sciatic nerve (patient with transfemoral amputation) (short axis of the nerve)

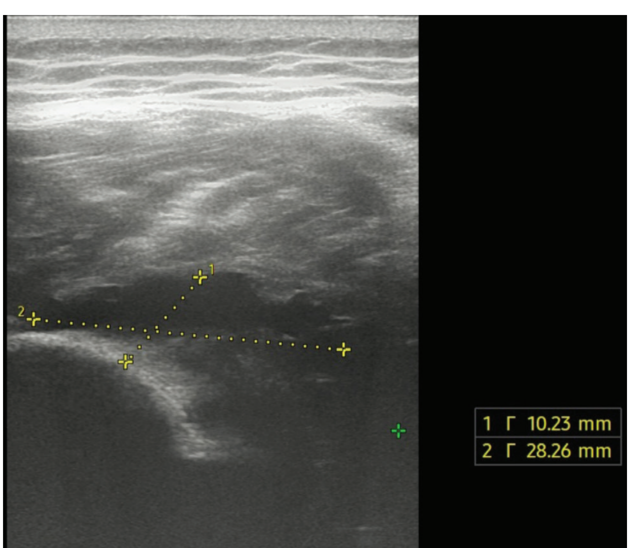

Fig. 5. Post-traumatic haematoma of the upper limb stump (patient with transhumeral amputation) (short axis of the bone)

Table 2 summarizes the distribution of residual limb pathologies identified on US and their clinical correlations. The most frequently observed abnormality was **neuroma (18%)**, typically presenting with sharp, localized neuropathic pain that could be reliably reproduced by probe compression. **Scar tethering or contracture (22%)** was the second most common finding, associated with pulling-type pain and reduced soft tissue mobility, often exacerbated during prosthetic use. **HO (13%)** manifested as hyperechoic foci with acoustic shadowing and was correlated with deep, aching pain and mechanical difficulties in prosthetic fitting. **Prosthesis-related soft tissue lesions (18%)**, including bursal swelling, hematomas, and edema, were frequently linked to pain during ambulation and prosthesis wear. Finally, **infection or abscess formation (12%)** was observed in a minority of patients, yet carried high clinical relevance, as it was associated with persistent pain, discharge, and local swelling, sometimes requiring surgical or antimicrobial intervention.

Table 3 demonstrates the frequency of overlapping sonographic abnormalities among patients with RLP. A substantial proportion of patients exhibited **more than one pathological feature** on US. While **40%** of individuals presented with a **single abnormality**, the majority (**42%**) demonstrated **2 coexisting findings**, most commonly a combination of neuroma with scar tethering or HO. Notably, **18%** of patients exhibited **3 or more concurrent sonographic abnormalities**, highlighting the complex and multifactorial nature of RLP in the late rehabilitation period. These results emphasize that in many cases, stump pain cannot be attributed to a single etiology, but rather arises from the interplay of neuropathic, mechanical, and inflammatory mechanisms.

RLP constitutes one of the most challenging sequels of limb amputation, with prevalence estimates reaching up to 80% of affected individuals [1, 8–11]. Its etiopathogenesis is multifactorial, encompassing peripheral mechanisms such as neuroma formation, HO, infection, and scar contracture, as well as central sensitization processes and maladaptive cortical reorganization [12–15]. Accurate delineation of structural correlates is of paramount importance, as these not only guide targeted interventions but also provide mechanistic insights into the perpetuation of chronic pain states. In the present study, neuromas represented the most frequent abnormality, corroborating prior evidence identifying neuroma formation as a central driver of neuropathic RLP [16–19]. Ultrasonography allowed direct visualization of hypoechoic fusiform nerve swellings with continuity to the parent nerve and provided dynamic correlation via reproduction of pain upon probe compression, consistent with previous observations [17]. Importantly, ultrasonography has expanded its role beyond diagnostics, serving as a real-time navigation tool for perineural injections, cryoablation, and targeted muscle reinnervation, which have demonstrated efficacy in neuroma-related pain [18–22]. Furthermore, experimental approaches such as nerve matrix scaffolds [22] and pharmacologic modulation of dorsal root ganglion ectopia [18–22] suggest a rapidly evolving therapeutic landscape wherein imaging plays an essential enabling role. HO emerged as the second most prevalent finding, in line with previous reports linking HO to nociceptive RLP and prosthetic intolerance, particularly in combat trauma populations [14–20]. Of note, ultrasonography facilitated early recognition of ossific foci preceding radiographic detection, underscoring its sensitivity for preclinical monitoring and potential utility in initiating prophylactic measures.

Infectious complications, documented in 12% of patients, highlight the vulnerability of amputation stumps to contaminated wartime wounds [18–22]. Ultrasonography proved highly sensitive in identifying hypoechoic collections with hyperemic rims on Doppler, thereby offering timely detection and guiding aspiration or debridement. Scar tethering and contracture (22%) constituted another significant source of pain, characterized by fascial immobility and traction symptoms. Dynamic ultrasonography provided a unique diagnostic value in capturing the loss of fascial glide, an underappreciated yet clinically meaningful correlate of functional restriction [3–5]. Prosthesis-related lesions (18%) further underscore the specificity of this patient population; bursitis, hematomas, and interface edema were readily identified by ultrasonography, enabling early prosthetic modification and preventing chronic irritation.

The high proportion of patients presenting with multiple abnormalities (≥ 2 findings in 60%) reflects the polyetiologic nature of RLP and reinforces the conceptual framework of overlapping nociceptive and neuropathic generators [18–22]. Peripheral nociceptive drive from neuromas, HO, and scar tethering likely facilitates central sensitization, which in turn amplifies pain persistence and refractoriness [18–22]. This integrative pathophysiology underscores the necessity of multimodal diagnostics that combine structural imaging, neurophysiology, and psychometric assessment.

Table 2

Sonographic findings

Sonographic findings	Frequency (%)	Clinical correlation
Neuroma	18	Localized sharp pain; reproduced by probe pressure
HO	13	Deep aching pain; difficulty with prosthesis fitting
Infection/ abscess	12	Persistent pain, discharge, swelling
Scar tethering / contracture	22	Pulling pain; reduced mobility
Prosthesis-related lesions	18	Pain during walking/usage; bursal swelling

Note: HO – heterotopic ossification.

Table 3

Coexistence of findings

Number of sonographic abnormalities, findings	Patients (%)
1	40
2	42
≥ 3	18

When compared with MRI and CT, ultrasonography exhibits distinct advantages: portability, real-time dynamic maneuvers, bedside feasibility in rehabilitation settings, and avoidance of ionizing radiation [3, 7]. While operator dependence remains a limitation, the cumulative evidence positions ultrasonography as a first-line modality in the diagnostic work-up of RLP. Its role extends to interventional domains, where it supports precision-guided therapies such as cryoablation, local injections, and novel regenerative approaches [8–12].

The limitations of this study include its single-center design and lack of systematic cross-validation with MRI in all patients. Nevertheless, by systematically characterizing ultrasonographic signatures of RLP in a large cohort of war-related amputees, the present findings advance the evidence base for US as both a diagnostic and therapeutic platform. Future directions should include multicenter studies, integration of ultrasonography with machine learning for automated lesion classification [3], and longitudinal tracking of treatment outcomes to refine patient-specific management algorithms.

CONCLUSIONS

US is a reliable first-line modality for the evaluation of RLP after amputation. It enables bedside, dynamic, and symptom-reproducing assessment of key pathological entities such as neuromas, HO, infection, scar tethering, and prosthesis-related complications. Its accessibility, safety, and ability to guide targeted interventions position US as an essential component of modern diagnostic algorithms for both military and civilian amputees.

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Стаття надійшла до редакції 09.11.2025. – Дата першого рішення 18.11.2025. – Стаття подана до друку 20.12.2025