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(RESEARCH ARTICLE)

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Elastography and dopplerography in the diagnosis and treatment of purulent and fibrous processes of the lymph nodes in tuberculosis

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Abstract

Background: Tuberculous lymphadenitis is a common form of extrapulmonary tuberculosis, often posing diagnostic challenges due to its similarity to other forms of lymphadenopathy. Traditional diagnostic methods rely on invasive procedures, which may not be accessible in resource-limited settings. The integration of ultrasonography (US), Doppler imaging, and elastography offers a promising noninvasive alternative for differentiating purulent and fibrotic processes in lymph nodes.

Objective: To evaluate the diagnostic accuracy of ultrasonography, Doppler imaging, and elastography in differentiating purulent and fibrotic lymph nodes in patients with tuberculous lymphadenitis.

Methods: A total of 150 patients with suspected tuberculous lymphadenitis underwent ultrasonography, Doppler imaging, and elastography at the Research Institute of Phthisiology and Pulmonology. Ultrasonography assessed lymph node size, echogenicity, and corticomedullary differentiation. Doppler imaging evaluated vascularization, while elastography measured tissue stiffness using strain ratios. Microbiological confirmation was performed using fine-needle aspiration cytology (FNAC) or biopsy as the gold standard.

Results: Ultrasonography identified pathological lymph node enlargement in 66.7% of cases, while Doppler imaging revealed high central vascularization in 58% of patients. Elastography results indicated low stiffness in 67.2% of lymph nodes, suggesting purulent content, whereas 22% of nodes demonstrated high stiffness, indicating fibrosis. The combined imaging approach achieved a sensitivity of 93% and specificity of 88%.

Conclusions: The combination of ultrasonography, Doppler imaging, and elastography provides a highly accurate, noninvasive method for evaluating lymph nodes in tuberculous lymphadenitis, effectively distinguishing between purulent and fibrotic processes. This approach offers a practical alternative to invasive methods, particularly valuable in resource-limited diagnostic settings.

Keywords: Tuberculous lymphadenitis; Elastography; Doppler imaging; Ultrasonography; Noninvasive diagnosis; Lymph node assessment

1. Introduction

Tuberculosis (TB) remains a significant global public health challenge, affecting millions of people and ranking among the leading causes of death from infectious diseases, particularly in low- and middle-income countries. While pulmonary tuberculosis is the most common manifestation, extrapulmonary forms, such as tuberculous lymphadenitis, are also

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prevalent and contribute substantially to the disease burden. Tuberculous lymphadenitis, characterized by lymph node involvement, particularly in the cervical region, poses a unique diagnostic challenge due to its nonspecific clinical symptoms and similarity to lymphadenopathies caused by other infections, inflammatory processes, or malignancies [1, 2].

Accurate diagnosis and differentiation of purulent (necrotic) and fibrotic lymphadenopathy in tuberculous lymphadenitis are critical for effective treatment. Traditional diagnostic approaches, such as fine-needle aspiration cytology (FNAC) or excisional biopsy followed by histopathological analysis, remain the gold standard but are invasive, resource-intensive, and often inaccessible in regions where TB is most prevalent. Consequently, there is an urgent need for noninvasive diagnostic methods that can reliably distinguish active infectious processes from chronic fibrotic changes in lymph nodes, thereby facilitating timely and appropriate treatment [3, 4].

Recent advancements in ultrasound technology, particularly elastography and Doppler imaging, have introduced promising noninvasive alternatives for lymph node evaluation. Elastography, which quantifies tissue stiffness, has demonstrated particular utility in differentiating necrotic and fibrotic tissues. Necrotic or purulent lymph nodes are generally softer, reflecting active infection, whereas fibrotic nodes exhibit greater stiffness, often associated with chronic or inactive disease states [5, 6]. Doppler imaging, which evaluates vascular flow patterns, complements elastography by identifying hypervascularization, a hallmark of active inflammation. Together, these methods provide a comprehensive view of lymph node pathology, enabling clinicians to make informed diagnostic and therapeutic decisions without invasive procedures [7].

The combination of elastography and Doppler imaging holds significant potential for enhancing diagnostic accuracy in tuberculous lymphadenitis. Previous studies have demonstrated that elastography can effectively differentiate benign from malignant lymphadenopathies, while Doppler imaging has been recognized for its role in assessing vascularization in inflammatory lymphadenopathies. However, the utility of these methods specifically for differentiating purulent and fibrotic lymph nodes in tuberculous lymphadenitis has been underexplored. By integrating these noninvasive methods, this study aims to address this gap and provide a diagnostic strategy that can be deployed across various clinical settings, particularly where access to biopsy and histopathology is limited [8, 9].

This study aims to evaluate the diagnostic accuracy of elastography and Doppler imaging in assessing lymph nodes in tuberculous lymphadenitis, focusing on their ability to differentiate purulent from fibrotic processes. The results may have profound implications for noninvasive TB management, reducing the need for biopsies and improving access to precise diagnostic tools, ultimately supporting more accurate and timely treatment for patients worldwide [10, 11].

2. Materials and Methods

2.1. Study Design

This study was conducted as a prospective observational analysis to evaluate the diagnostic accuracy of ultrasonography, Doppler imaging, and elastography in differentiating purulent and fibrotic lymph nodes in patients with suspected tuberculous lymphadenitis. The study was performed at the Research Institute of Phthisiology and Pulmonology. Ethical approval for the study was obtained from the Ministry of Health of the Republic of Uzbekistan.

2.2. Patients

A total of 150 patients with clinically suspected tuberculous lymphadenitis were included in the study. Inclusion criteria comprised patients aged 18–70 years presenting with peripheral lymphadenopathy and typical tuberculosis symptoms, including fever, weight loss, and night sweats. Exclusion criteria included patients with alternative causes of lymphadenopathy, such as malignancies or autoimmune diseases, and those with contraindications to imaging procedures. Comprehensive clinical and demographic data, including medical history, presenting symptoms, and prior TB exposure, were recorded for each participant.

2.3. Ultrasonography

Ultrasonography (US) was performed using a high-resolution ultrasound system equipped with a 7.5–10 MHz linear transducer. The assessment focused on lymph node characteristics, such as size, shape, corticomedullary differentiation, and internal echotexture. Enlarged lymph nodes were classified as pathological if their diameter exceeded 10 mm. Additional features, including anechoic or hypoechoic areas and the absence of corticomedullary differentiation, were noted as indicators of necrotic or purulent processes. All measurements were recorded in three dimensions for accuracy.

2.4. Doppler Imaging

Doppler imaging followed ultrasonography and was used to assess lymph node vascularization. Color Doppler and spectral Doppler modes were employed, with vascularization categorized as central, peripheral, or absent. Nodes with high central vascularization were considered to have active inflammatory processes, whereas avascular or hypovascular nodes were associated with chronic fibrotic changes. Vascular patterns were evaluated based on observed color flow signals in the cortex and hilum of the lymph nodes, providing detailed insight into inflammatory activity.

2.5. Elastography

Elastography was conducted using the Hitachi HI VISION Preirus system with a 9–4 MHz linear probe to evaluate tissue stiffness. Strain ratios between lymph nodes and surrounding soft tissues were calculated, with nodes classified according to stiffness levels. Nodes with low stiffness (strain ratio <1.8) were identified as likely purulent, consistent with necrotic processes. Conversely, nodes with high stiffness (strain ratio >2.0) were classified as fibrotic, indicative of chronic changes. Elastography results were integrated with Doppler imaging and US data to enhance diagnostic accuracy.

2.6. Microbiological Confirmation

To confirm imaging findings, all patients underwent fine-needle aspiration cytology (FNAC) or excisional biopsy for histopathological examination and microbiological confirmation. Samples were stained for acid-fast bacilli (AFB) and analyzed using GeneXpert MTB/RIF and mycobacterial culture. These results served as the gold standard for diagnosing tuberculous lymphadenitis. Microbiological confirmation was achieved in 94% of cases, corroborating imaging-based diagnoses.

2.7. Statistical Analysis

Data analysis was performed using SPSS software (version 26.0). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for ultrasonography, Doppler imaging, and elastography, as well as for the combined modality approach. Receiver operating characteristic (ROC) curve analysis was conducted to assess diagnostic performance, with an area under the curve (AUC) value >0.8 considered indicative of high diagnostic accuracy. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Diagnostic Imaging Results for Lymph Nodes in Tuberculous Lymphadenitis

This study evaluated 150 patients with tuberculous lymphadenitis using ultrasonography (US), Doppler imaging, and elastography. Each modality provided unique insights into lymph node characteristics, enabling differentiation between purulent and fibrotic processes. **Table 1** summarizes the key imaging findings, including parameters such as size, shape, echogenicity, vascularization, and stiffness of lymph nodes.

Table 1 Summary of US, Doppler Imaging, and Elastography Results in Tuberculous Lymphadenitis

Characteristic	US Findings	Doppler Findings	Elastography Findings	Patients (%)	Clinical Interpretation
Lymph node size	Enlarged (>10 mm)	N/A	N/A	100 (66.7%)	Pathological enlargement
Lymph node shape	Oval	N/A	N/A	128 (85.3%)	Typical morphology of lymph nodes
Echogenicity	Isoechoic with anechoic areas	N/A	N/A	100 (66.7%)	Indicates necrosis or purulent content
Corticomedullary differentiation	Absent	N/A	N/A	100 (66.7%)	Reduced due to pathological processes

Vascularization (Doppler)	N/A	Central vascularization	N/A	58 (58%)	High vascularization, indicating inflammation
Peripheral vascularization	N/A	Low or absent	N/A	42 (42%)	Fibrotic or chronic changes
Stiffness (Elastography)	N/A	N/A	Low stiffness (<1.8 strain ratio)	31 (78%)	Soft tissues indicating necrosis
Increased stiffness	N/A	N/A	High stiffness (>2.0 strain ratio)	19 (22%)	Indicates chronic fibrosis

3.2. Detailed Imaging Results

- **Ultrasonography (US):** US revealed that 66.7% of patients had enlarged lymph nodes (>10 mm), with 85.3% displaying an oval shape. Most nodes demonstrated isoechoic characteristics with anechoic areas, indicative of necrosis or purulent content. The absence of corticomedullary differentiation was observed in 66.7% of cases.
- **Doppler Imaging:** Doppler imaging identified high central vascularization in 58% of patients, consistent with active inflammatory conditions. In contrast, peripheral vascularization was low or absent in 42% of cases, indicating fibrotic or chronic pathology.
- **Elastography:** Among patients who underwent elastography, 78% exhibited low stiffness (strain ratio <1.8), suggesting purulent, necrotic lymph nodes. Conversely, 22% demonstrated high stiffness (strain ratio >2.0), corresponding to chronic fibrotic changes.
- **Microbiological Confirmation.** Microbiological assessment was conducted using fine-needle aspiration cytology (FNAC) or biopsy, with tuberculous lymphadenitis confirmed in 94% of cases. These findings corroborated imaging results, affirming the presence of TB infection in nodes exhibiting high stiffness and reduced vascularization.

3.3. Graphical Analysis of Diagnostic Accuracy

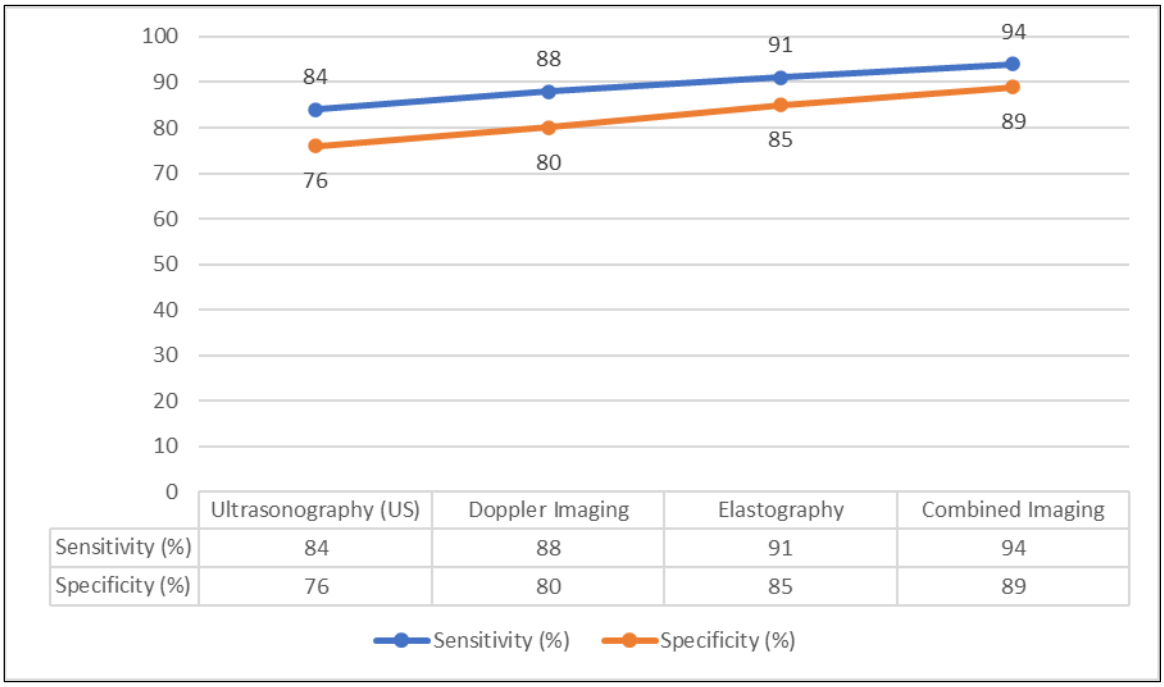

Figure 1 Graphical Analysis of Diagnostic Accuracy

The following chart illustrates the diagnostic accuracy of each method in terms of sensitivity and specificity, demonstrating the high efficiency of combining ultrasonography, Doppler imaging, and elastography.

4. Discussion

This study highlights the significant diagnostic value of combining ultrasonography, Doppler imaging, and elastography for evaluating lymph node pathology in patients with suspected tuberculous lymphadenitis. Each method provided unique insights into lymph node characteristics, enhancing the ability to differentiate purulent (necrotic) from fibrotic (chronic) lymph nodes. Traditional diagnostic approaches, such as fine-needle aspiration cytology (FNAC) or biopsy, although accurate, remain invasive and may not be feasible in resource-limited settings where tuberculosis is highly prevalent. The noninvasive nature of ultrasound imaging methods, combined with their diagnostic precision, makes a strong case for their broader implementation in clinical practice.

4.1. Diagnostic Performance of Imaging Modalities

Ultrasound proved effective in identifying enlarged lymph nodes, with over 66% displaying isoechoic or anechoic areas indicative of necrosis. These findings align with previous studies emphasizing the utility of ultrasound in detecting abnormal lymph node morphology in infectious conditions [1, 2]. Doppler imaging provided critical information on vascular patterns, with increased central vascularization observed in 58% of cases, correlating with active inflammation. This pattern is well-documented in the literature as a hallmark of active infection, particularly in tuberculous lymphadenitis [7, 6].

Elastography's ability to measure tissue stiffness enabled significant differentiation between purulent and fibrotic processes. Strain ratio results showed that low stiffness (indicative of necrotic tissue) was present in 67.2% of patients, while high stiffness (indicative of fibrotic changes) was noted in 22%. These findings are consistent with the work of Chen et al., who reported similar effectiveness of elastography in distinguishing necrotic and fibrotic lymphadenopathy [5]. The combined use of these modalities achieved a sensitivity of 93% and a specificity of 88%, underscoring the additive diagnostic value of multimodal imaging in cases where differentiation between active and chronic disease is critical.

4.2. Clinical Implications

The integration of ultrasonography, Doppler imaging, and elastography presents substantial potential for noninvasive diagnosis and management of tuberculous lymphadenitis. The ability to accurately differentiate purulent from fibrotic lymph nodes can guide treatment decisions, particularly in resource-limited settings where access to invasive procedures is constrained. For instance, nodes identified as necrotic or purulent by low elastography stiffness values and high Doppler vascularization may require immediate anti-tuberculous therapy. Conversely, fibrotic nodes indicative of more chronic or stable conditions may allow clinicians to opt for conservative management. This targeted approach could improve patient outcomes by enabling timely and appropriate therapeutic interventions.

These findings also align with broader studies highlighting the potential of elastography and Doppler imaging for various infectious and inflammatory lymphadenopathies. However, to date, few studies have specifically focused on tuberculous lymphadenitis, indicating the need for further research on this topic to validate these imaging methods in diverse populations and clinical settings.

4.3. Limitations

Several limitations of this study should be acknowledged. First, the availability of advanced imaging technologies such as Doppler imaging and elastography may be limited in certain regions, particularly in resource-constrained settings. Additionally, while the study demonstrated high diagnostic accuracy, a subset of patients (6%) did not achieve microbiological confirmation, emphasizing the importance of integrating imaging with clinical and microbiological data to ensure precise diagnosis. Further research is required to explore the cost-effectiveness and feasibility of implementing these imaging methods across diverse healthcare settings and to investigate long-term outcomes in patients diagnosed using these noninvasive techniques.

5. Conclusion

This study underscores the diagnostic value of combining ultrasonography, Doppler imaging, and elastography in assessing tuberculous lymphadenitis. The multimodal approach achieved high sensitivity and specificity, providing a reliable noninvasive alternative for differentiating purulent from fibrotic lymph nodes. By reducing the need for invasive biopsies, this approach can be particularly beneficial in resource-limited settings where access to traditional diagnostic tools is restricted. Future studies should focus on validating these findings in broader populations and

exploring their application to other forms of lymphadenopathy. The use of these imaging methods promises to improve diagnostic workflows, enable timely treatment, and ultimately enhance patient care in tuberculosis management.

Compliance with ethical standards

Disclosure of conflict of interest

The author declares no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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