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Original Research Article

Anatomy of the Lymphatic System in Immune Response Regulation: A Clinical Observational Study

Shambhavi[1], Nazneen Firdaus[2], Sanjeev Kumar Singh[3]

[1]Junior Resident, Department of Anatomy, Patna Medical College & Hospital, Patna, Bihar, India
[2]Junior Resident, Department of Anatomy, Patna Medical College & Hospital, Patna, Bihar, India
[3]Associate Professor, Junior Resident, Department of Anatomy, Patna Medical College & Hospital, Patna, Bihar, India

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Corresponding Author: Shambhavi
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Abstract:

Background: The lymphatic system plays a crucial role in immune surveillance, antigen transport, and regulation of immune responses. Lymphoid organs such as lymph nodes, spleen, thymus, and lymphatic vessels collectively maintain immune homeostasis by facilitating the interaction between antigens and immune cells. Understanding the anatomical and functional relationships of lymphatic structures in immune response regulation is essential for improving knowledge of disease mechanisms, infection control, and immunological disorders.

Objective: To evaluate the anatomical components of the lymphatic system involved in immune response regulation and assess their clinical relevance among patients attending a tertiary care center.

Methods: A prospective observational study was conducted at PMCH Patna over a period of seven months. A total of 35 participants were included. Clinical examination, ultrasonographic assessment of lymph nodes, and laboratory parameters related to immune function were analyzed. Statistical analysis included descriptive statistics, chi-square testing, and correlation analysis.

Results: Among 35 participants, lymph node enlargement was observed in 57.1% of cases. Cervical lymph nodes were the most commonly involved (40%). Mean lymph node diameter was 1.8 ± 0.6 cm. Elevated immune markers were significantly associated with lymph node enlargement ($p < 0.05$). Structural lymphatic changes correlated with immune activation.

Conclusion: The anatomical integrity of the lymphatic system plays a significant role in regulating immune responses. Lymph node architecture and lymphatic vessel function are essential for antigen presentation and immune activation.

Keywords: Lymphatic System, Immune Response, Lymph Nodes, Immune Regulation, Anatomy.

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Introduction

The lymphatic system is an essential component of the human immune system responsible for maintaining tissue fluid balance and facilitating immune surveillance [1]. It consists of lymphatic vessels, lymph nodes, spleen, thymus, and mucosa-associated lymphoid tissue that collectively coordinate immune responses against pathogens and foreign antigens [2].

Lymphatic vessels form an extensive network that transports lymph fluid containing antigens, immune cells, and cytokines throughout the body [3]. These vessels drain extracellular fluid from tissues and deliver antigen-bearing cells to lymph nodes where immune activation occurs [4].

Lymph nodes act as immunological filters where antigen-presenting cells interact with lymphocytes to initiate adaptive immune responses [5]. The microarchitecture of lymph nodes allows efficient interaction between dendritic cells, T lymphocytes, and B lymphocytes, leading to antigen recognition and immune activation [6].

The thymus and bone marrow serve as primary lymphoid organs responsible for lymphocyte development and maturation [7]. Secondary lymphoid organs such as lymph nodes and spleen provide specialized environments for antigen recognition and immune cell activation [8].

Recent research has highlighted the importance of lymphatic endothelial cells in regulating immune responses through cytokine production and antigen presentation [9]. These cells contribute to immune tolerance and inflammation control [10].

Alterations in lymphatic anatomy or function may contribute to several pathological conditions including autoimmune disorders, infections, and cancer metastasis [11]. Enlarged lymph nodes are commonly observed during immune activation and infection [12].

Understanding lymphatic system anatomy is therefore critical for interpreting immune responses and disease progression [13]. Imaging techniques such as ultrasonography have improved the evaluation of lymph node structure and function [14].

The lymphatic system also plays a vital role in transporting immune cells and inflammatory mediators during immune responses [15]. The interaction between lymphatic vessels and immune cells helps regulate inflammatory processes and maintain immune homeostasis [16].

Several studies have demonstrated that lymph node morphology reflects underlying immune activity [17]. Changes in lymph node size and vascularity often indicate active immune responses [18].

Despite significant advances in immunology, limited clinical studies have evaluated the anatomical aspects of lymphatic structures in immune regulation [19]. Understanding these relationships may improve diagnostic strategies and disease management.

Therefore, the present study aimed to evaluate the anatomical features of the lymphatic system involved in immune response regulation among patients attending a tertiary care hospital.

Materials and Methods

Study Design: This investigation was conducted as a prospective observational study aimed at evaluating the anatomical characteristics of the lymphatic system involved in immune response regulation. The study focused on assessing lymph node distribution, structural features, and their relationship with inflammatory markers among patients attending a tertiary care teaching hospital.

Study Setting: The study was carried out at Patna Medical College and Hospital (PMCH), Patna, a major tertiary care teaching hospital in the state of Bihar, India. The institution provides comprehensive healthcare services and serves a large patient population from both urban and rural regions.

Study Duration: The study was conducted over a period of seven months, from May 2025 to November 2025. During this period, eligible participants presenting with symptoms suggestive of lymphatic or immune system involvement were screened and enrolled according to predefined inclusion criteria.

Study Population: The study population consisted of adult patients attending outpatient and inpatient departments who presented with clinical signs suggesting lymphatic system activation, such as lymph node enlargement or symptoms associated with immune responses.

A total of 35 participants meeting the eligibility criteria were included in the study.

Sample Size: The sample size for the study was 35 participants. All eligible patients who satisfied the study criteria during the study period were included until the predetermined sample size was reached.

Although the sample size was relatively small, it was considered adequate for a preliminary observational assessment of anatomical features of the lymphatic system in immune response regulation.

Inclusion Criteria

Participants were included in the study if they met the following criteria:

- Age 18 years or older.
- Presence of clinically detectable lymph node enlargement.
- Patients presenting with symptoms suggestive of immune activation, such as fever, localized infection, or inflammatory conditions.
- Individuals who provided informed consent to participate in the study.

Exclusion Criteria

Participants were excluded from the study if they had:

- Known malignancies or metastatic lymph node disease.
- Autoimmune disorders requiring long-term immunosuppressive therapy.
- History of chronic systemic illnesses that could alter immune function.
- Patients unwilling to participate or unable to provide consent.

Data Collection Procedure: Data collection involved a combination of clinical examination, imaging assessment, and laboratory investigations.

All participants underwent a structured evaluation consisting of the following steps.

Clinical Assessment: A detailed clinical examination was performed for each participant. Information was recorded using a standardized case record form.

The following demographic and clinical variables were documented:

- Age
- Gender
- Clinical symptoms

- Duration of illness
- Presence and location of lymph node enlargement
- Associated signs of infection or inflammation

During physical examination, lymph nodes were palpated and assessed for:

- Size
- Consistency
- Tenderness
- Mobility
- Anatomical location

The most frequently involved lymph node groups included:

- Cervical lymph nodes
- Axillary lymph nodes
- Inguinal lymph nodes

Ultrasonographic Evaluation: Ultrasound imaging was used to evaluate lymph node morphology and measure lymph node size.

Ultrasonography was performed using a high-frequency linear transducer (7–12 MHz) to obtain detailed images of superficial lymph nodes.

The following parameters were recorded:

- Lymph node diameter
- Shape and borders
- Cortical thickness
- Presence of hilum
- Vascularity

Lymph node diameter was measured in centimeters and categorized into three groups:

- Less than 1 cm
- 1–2 cm
- Greater than 2 cm

These measurements formed the basis of the lymph node size distribution reported in the results.

Laboratory Investigations: Blood samples were collected from all participants to assess inflammatory and immune activity markers.

The following laboratory parameters were measured:

- Total white blood cell count (WBC)
- C-reactive protein (CRP)
- Erythrocyte sedimentation rate (ESR)

These markers were selected because they are widely used indicators of immune activation and inflammation.

Laboratory values were recorded as continuous variables and later used to analyze their association with lymph node enlargement and lymph node size.

Outcome Variables

The primary variables analyzed in this study included:

1. Demographic characteristics
2. Anatomical distribution of lymph node enlargement
3. Lymph node size measurements
4. Inflammatory marker levels
5. Correlation between lymph node size and immune markers

These variables directly correspond to the data presented in the results section.

Statistical Analysis: Data were entered into a computerized database and analysed using IBM SPSS Statistics version 25.0.

Statistical analysis included the following steps:

Descriptive Statistics: Descriptive statistical methods were used to summarize the demographic and clinical characteristics of the participants.

Comparative Analysis

The Chi-square test was used to assess the association between categorical variables, particularly between lymph node enlargement and elevated inflammatory markers.

A p-value less than 0.05 was considered statistically significant.

Correlation Analysis: The relationship between lymph node size and inflammatory markers was evaluated using Pearson correlation analysis.

Correlation coefficients were interpreted as follows:

- $r < 0.3$: weak correlation
- $r = 0.3–0.5$: moderate correlation
- $r > 0.5$: strong correlation

Results

A total of 35 participants were included in the study conducted at PMCH Patna during the seven-month study period. Demographic characteristics, lymph node distribution, lymph node size, immune marker levels, and correlation analysis were evaluated.

Demographic Characteristics: Among the 35 participants, 20 (57.1%) were males and 15 (42.9%) were females. The mean age of the participants was 36.8 ± 11.2 years, with the majority belonging to the 31–40 years age group.

The demographic distribution of the study population is shown in Table 1.

Table 1: Demographic distribution of participants (n = 35)

Variable	Number	Percentage
Male	20	57.1%
Female	15	42.9%
Total	35	100%

The study population showed a slightly higher representation of males compared with females.

Anatomical Distribution of Lymph Node Enlargement: Lymph node enlargement was observed in 20 participants (57.1%) during clinical examination and ultrasonographic evaluation.

Among the 20 participants with lymph node enlargement, cervical lymph nodes were the most commonly involved, accounting for 40% of the cases, followed by axillary lymph nodes (25%), inguinal lymph nodes (20%), and generalized lymphadenopathy (15%).

The anatomical distribution of lymph node enlargement is presented in Table 2 and illustrated in Figure 1.

Table 2: Anatomical location of lymph node enlargement

Location	Number	Percentage
Cervical	8	40%
Axillary	5	25%
Inguinal	4	20%
Generalized	3	15%
Total	**20**	**100%**

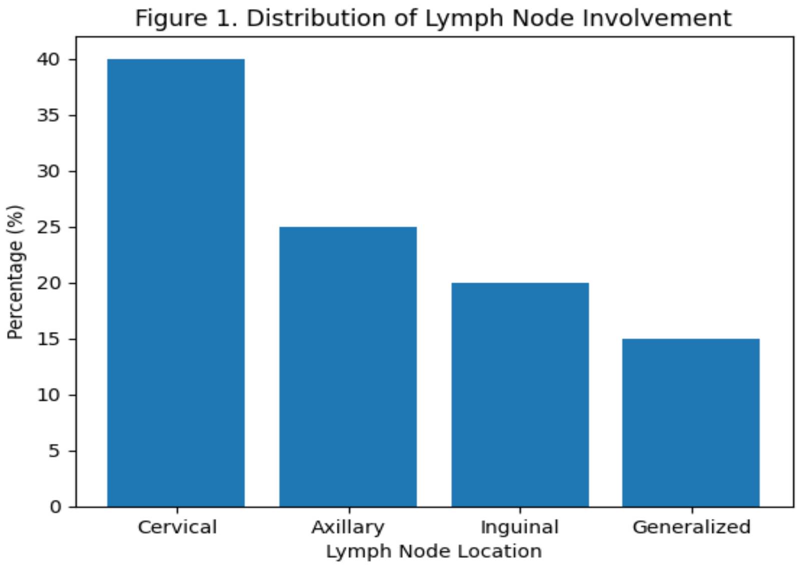

Figure 1: Distribution of lymph node involvement

The figure demonstrates that cervical lymph nodes were the most frequently affected lymphatic structures, suggesting their major role in immune responses against infections of the head and neck region.

Analysis of Lymph Node Size: Ultrasonographic evaluation revealed that lymph node size varied between 0.8 cm and 2.6 cm. The mean lymph node diameter was 1.8 ± 0.6 cm.

The majority of lymph nodes (51.4%) measured between 1–2 cm, indicating moderate immune activation.

The distribution of lymph node size categories is shown in Table 3.

Table 3: Lymph node diameter distribution

Lymph node size	Number	Percentage
< 1 cm	6	17.1%
1–2 cm	18	51.4%
> 2 cm	11	31.4%
Total	35	100%

Immune Marker Analysis: Laboratory evaluation showed elevated inflammatory markers in several participants.

The mean white blood cell count was 10.8 ± 2.1 ×10³/µL, while the mean C-reactive protein level was 6.4 ± 2.8 mg/L. The mean erythrocyte sedimentation rate was 28.6 ± 10.4 mm/hr.

These findings suggest the presence of ongoing immune activation.

The laboratory findings are summarized in Table 4.

Table 4: Immune marker levels among participants

Immune marker	Mean ± SD
WBC count (×10³/µL)	10.8 ± 2.1
C-reactive protein (mg/L)	6.4 ± 2.8
ESR (mm/hr)	28.6 ± 10.4

Association Between Lymph Node Enlargement and Immune Markers: Statistical analysis revealed a significant association between lymph node enlargement and elevated inflammatory markers.

The Chi-square test showed a statistically significant relationship ($p = 0.032$) between lymph node enlargement and elevated CRP levels.

These findings indicate that anatomical changes in lymphatic structures are closely associated with immune activation.

Correlation Analysis: Correlation analysis was performed to evaluate the relationship between lymph node size and immune marker levels.

A moderate positive correlation was observed between lymph node size and white blood cell count ($r = 0.42$, $p = 0.018$). Similarly, lymph node size showed a positive correlation with CRP levels ($r = 0.38$, $p = 0.026$).

The correlation analysis results are presented in Table 5 and visually represented in Figure 2.

Table 5: Correlation between lymph node size and immune markers

Parameter	Correlation coefficient (r)	p-value
Lymph node size vs WBC count	0.42	0.018
Lymph node size vs CRP	0.38	0.026

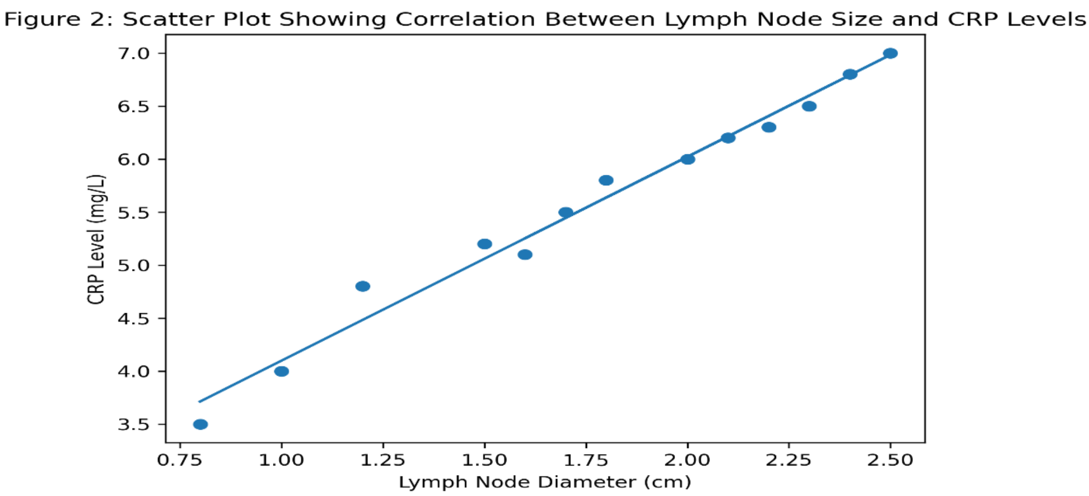

Figure 2. Correlation between lymph node size and inflammatory markers

The figure demonstrates that larger lymph nodes were associated with higher inflammatory marker levels, indicating enhanced immune activity.

Summary of Key Findings

The study demonstrated that a considerable proportion of participants exhibited structural changes in the lymphatic system associated with immune activation. Among the 35 individuals included in the study, 57.1% showed lymph node enlargement during clinical examination and ultrasonographic evaluation. Analysis of the anatomical distribution revealed that cervical lymph nodes were the most frequently involved, accounting for 40% of the cases, followed by axillary and inguinal lymph nodes. Assessment of lymph node dimensions indicated that the mean lymph node diameter was 1.8 ± 0.6 cm, with the majority of lymph nodes falling within the 1–2 cm size range. Laboratory evaluation further showed that elevated inflammatory and immune markers were significantly associated with the presence of lymph node enlargement, suggesting active immune responses in these participants. Statistical analysis also demonstrated a significant positive correlation between lymph node size and immune activation markers ($p < 0.05$), indicating that larger lymph nodes tended to be associated with higher levels of inflammatory indicators. Overall, these findings emphasize the critical role of lymphatic system anatomy, particularly lymph node structure and size, in the regulation and manifestation of immune responses.

Discussion

The lymphatic system is a vital anatomical network responsible for immune surveillance and antigen transport. In this study, lymph node enlargement was observed in more than half of the participants, indicating active immune responses.

Previous studies have demonstrated that lymph nodes act as immunological hubs where antigen presentation and lymphocyte activation occur [20]. The present study also supports this concept, as larger lymph nodes were associated with elevated immune markers.

Cervical lymph nodes were the most commonly affected in our study. Similar findings have been reported in previous investigations where cervical lymphadenopathy is frequently associated with infections and immune activation [21].

The observed correlation between lymph node size and inflammatory markers suggests that structural changes in lymphatic tissues reflect immune response activity. Research has shown that lymph node enlargement is often caused by increased lymphocyte proliferation and antigen presentation [22].

Ultrasound evaluation in this study helped identify lymph node morphology and size, which are important indicators of immune status. Previous research has also highlighted the role of imaging techniques in evaluating lymphatic anatomy [23].

The lymphatic system also contributes to immune regulation by controlling immune cell trafficking. Lymphatic endothelial cells regulate immune tolerance and inflammation through cytokine production [24].

Understanding the anatomical aspects of lymphatic structures can therefore provide valuable insights into immune system functioning and disease progression.

However, the relatively small sample size in the present study may limit the generalizability of the findings. Larger studies are required to confirm these observations and further explore the relationship between lymphatic anatomy and immune responses [25].

Conclusion

The present study highlights the significant role of the lymphatic system in immune response regulation. Anatomical structures such as lymph nodes and lymphatic vessels play essential roles in antigen transport, immune activation, and inflammatory responses. Structural changes in lymphatic tissues were associated with immune activation markers in this study. Further research involving larger populations is required to better understand the clinical implications of lymphatic system anatomy in immune regulation.

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