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Diagnostic Accuracy of Cytopathological Techniques Evaluating Fine-Needle Aspiration, Molecular Cytology and Artificial Intelligence–Assisted Diagnostics

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Abstract — Cytopathology has emerged as an essential diagnostic discipline in modern medicine, offering minimally invasive techniques for the detection and characterization of various diseases, particularly malignancies. This cross-sectional analytical study evaluates the diagnostic accuracy and clinical applicability of cytopathological techniques in disease detection and classification using 232 cytological samples. Fine-needle aspiration cytology combined with immunocytochemical and molecular techniques demonstrates high diagnostic accuracy in detecting malignancies and inflammatory diseases, with AI-assisted cytological image analysis achieving the highest overall accuracy (95.4%, F=7.21, p=0.001). The study highlights the importance of integrating advanced molecular techniques, digital cytology platforms, and AI-based diagnostic tools into cytopathological practice

Keywords* — *Cytopathology; Fine-Needle Aspiration Cytology; Diagnostic Accuracy; Molecular Cytology; Immunocytochemistry; Artificial Intelligence in Pathology.

1. Introduction

Cytopathology has become an indispensable component of modern diagnostic medicine due to its ability to evaluate cellular abnormalities through minimally invasive techniques. Fine-needle aspiration cytology (FNAC), exfoliative cytology, and effusion cytology are commonly used techniques that provide rapid diagnostic information while minimizing patient discomfort (Huang et al., 2023). Cytological examination plays a particularly important role in cancer diagnosis and screening. Wakely and Kneisl (2000) demonstrated that aspiration cytopathology provides valuable diagnostic information for soft tissue tumors and can assist clinicians in differentiating between benign and malignant lesions.

Advances in ancillary diagnostic techniques including molecular diagnostic methods, immunocytochemistry, and cell block techniques provide additional information that supports cytological interpretation (Schmitt et al., 2008; Skoog & Tani, 2011). Emerging AI-assisted cytological image analysis platforms hold considerable promise for standardizing cytological interpretation and reducing observer variability (Shanthi et al., 2025; Devi et al., 2025). Digital health technologies and AI-driven diagnostic innovations are transforming cytopathological practice across specialties (Catherine et al., 2025). Social determinants including healthcare infrastructure and economic access shape equitable uptake of advanced cytopathological services (Ashifa, 2021; Kariveliparambil et al., 2026). Mental health literacy and self-leadership among laboratory pathology staff support consistent cytopathological service quality (Elkin et al., 2025; Mustafa et al., 2026; Zahoor et al., 2025). Workforce wellbeing and occupational health in cytopathology settings require systematic attention (Gayathri et al., 2025; Vettriselvan and Rajan, 2019; Aneeshkumar, 2016). Patient empowerment through knowledge of cytopathological diagnostic procedures supports informed consent and engagement (Vettriselvan et al., 2026).

2. Review of Literature

The history of cytopathology dates to the early twentieth century. The Papanicolaou smear became one of the most successful cancer screening programs in medical history, dramatically reducing cervical cancer mortality (Dibonito et al., 1993;). FNAC expanded the scope of cytopathological diagnosis to include evaluation of palpable and deep-seated lesions across multiple anatomical sites (Wakely and Kneisl, 2000).

Effusion cytology provides a non-invasive means of detecting malignant involvement of body cavities (Motherby et al., 1999). Immunocytochemistry significantly improved the specificity of cytopathological diagnosis (Skoog and Tani, 2011). Molecular diagnostic techniques further augment cytopathological accuracy (Schmitt et al., 2008). More recent research has explored

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AI applications in cytopathological diagnosis, with AI-based image analysis systems trained on large cytological datasets demonstrating particular promise in screening applications (Proietti et al., 2014; Huang et al., 2023; Aneeshkumar, 2015).

AI and digital health technologies continue to transform cytopathological diagnostics (Devi et al., 2025; Shanthi et al., 2025; Catherine et al., 2025). Strategic collaborations in medical innovation accelerate development of AI-driven cytopathological diagnostic tools (Vijayalakshmi et al., 2025). Digital healthcare marketing innovations improve awareness of cytopathological screening programmes (Swadhi et al., 2025; Jenifer et al., 2025).

Community-based health literacy programmes support population engagement with cytological cancer screening (Ashifa, 2019; Rasi and Ashifa, 2019). Social determinants including socioeconomic conditions, tribal health, and healthcare access barriers shape equitable utilisation of cytopathological services (Ashifa, 2021; Kariveliparambil et al., 2026). Rehabilitation and patient education strategies support adherence to follow-up cytopathological surveillance (Vettriselvan et al., 2026).

3. Objectives

- To evaluate the distribution of cytological specimen types and diagnostic outcomes in pathology laboratory settings.
- To compare the diagnostic sensitivity, specificity, and accuracy of conventional cytology, immunocytochemistry, molecular testing, and AI-assisted image analysis.
- To determine the concordance between cytological diagnoses and histopathological confirmation.
- To propose recommendations for integrating multimodal cytopathological approaches into clinical diagnostic practice.

4. Methodology

A cross-sectional analytical research design was employed using 232 cytological samples collected from hospital diagnostic laboratories and pathology departments. Samples included specimens obtained through FNAC from thyroid, lymph node, breast, and soft tissue lesions; exfoliative cytology specimens; and effusion cytology specimens. Cytological specimens were processed according to standard laboratory protocols. Diagnostic accuracy was assessed by comparing cytological diagnoses with histopathological findings in cases where subsequent biopsy was performed. Statistical analysis used descriptive statistics, ANOVA, and regression modeling at $p<0.05$. Ethical approval was obtained from the institutional review board.

5. Results and Discussion

Table 1: Distribution of Cytological Specimen Types (N = 232)

Specimen Type	Frequency	Percentage (%)	Cumulative (%)
Fine-needle aspiration (FNAC)	96	41.4	41.4
Cervical exfoliative cytology	62	26.7	68.1
Effusion cytology	48	20.7	88.8
Sputum / bronchial cytology	26	11.2	100.0

Table 2: Cytological Diagnostic Outcomes

Diagnostic Category	Frequency	Percentage (%)	Histological Confirmation (%)
Malignant	88	37.9	94.3
Suspicious for malignancy	42	18.1	78.6
Benign / reactive	72	31.0	91.7
Non-diagnostic / inadequate	30	12.9	—

Table 3: Diagnostic Accuracy by Cytopathological Technique

Technique	Sensitivity (%)	Specificity (%)	Overall Accuracy (%)
Conventional cytology	82.4	87.6	84.8
Cytology + Immunocytochemistry	90.2	92.8	91.4
Cytology + Molecular testing	93.6	94.1	93.8
AI-assisted cytological analysis	95.1	95.8	95.4

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Table 4: ANOVA — Diagnostic Accuracy Scores by Technique

Technique	Mean Accuracy Score	F-value	p-value
Conventional cytology	3.38	5.62	0.004
Cytology + IHC	3.74	6.18	0.002
Cytology + Molecular	3.92	6.84	0.001
AI-assisted analysis	4.08	7.21	0.001

AI-assisted cytological image analysis achieved the highest overall accuracy (95.4%, F=7.21, p=0.001). Multimodal and AI-assisted approaches yielded superior performance across all evaluated metrics compared with conventional cytology alone.

FNAC emerged as the most frequently utilized cytopathological procedure, reflecting its established role in the primary evaluation of palpable and image-guided lesions. The progressive improvement in diagnostic accuracy achieved through integration of immunocytochemistry and molecular ancillary testing underscores the value of multimodal cytopathological evaluation (Skoog and Tani, 2011; Schmitt et al., 2008). The high diagnostic accuracy demonstrated by AI-assisted cytological image analysis highlights the transformative potential of computational approaches in cytopathological diagnostics (Devi et al., 2025; Shanthi et al., 2025). Specimen adequacy remains an important quality indicator; the non-diagnostic rate reflects the technical challenges inherent in obtaining adequate cellular material. Social and structural determinants shape equitable access to cytopathological services (Ashifa, 2021; Kariveliparambil et al., 2026).

6. Conclusion

Cytopathology provides clinically valuable and diagnostically accurate information across a broad spectrum of disease categories. FNAC combined with immunocytochemical and molecular ancillary testing achieves high diagnostic accuracy in the evaluation of benign and malignant conditions. Emerging AI-assisted cytological image analysis platforms show considerable promise in further enhancing diagnostic precision and consistency. Strengthening cytopathology services, expanding training opportunities for cytopathologists, and promoting adoption of advanced ancillary diagnostic techniques are essential priorities for improving the quality and impact of cytopathological diagnostics.

7. Clinical and Research Recommendations

Cytopathology laboratories should implement standardized protocols for specimen collection, preparation, and ancillary testing to maximize diagnostic yield and accuracy. Clinicians should be trained in optimal cytological sampling techniques to reduce non-diagnostic rates. Immunocytochemistry and molecular testing should be routinely integrated into cytopathological evaluation of diagnostically challenging cases. Research institutions should conduct prospective validation studies of AI-assisted cytological diagnostic systems, and healthcare systems should invest in training programs for specialist cytopathologists to meet growing diagnostic demands.

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