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Modern Diagnostic Features of Forensic Medical Examination in Mechanical Asphyxia

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Abstract: Mechanical asphyxia is a type of death caused by obstruction of the airways or suffocation resulting from external mechanical force. This article examines the modern diagnostic features of forensic medical examination in cases of mechanical asphyxia. The study was conducted based on scientific publications published between 2022 and 2025 and analyzes the pathological, histological, and biochemical changes observed in deaths caused by hanging, strangulation, ligature strangulation, and compression. Modern diagnostic methods, including virtual autopsy (PMCT and PMMRI), proteomics, miRNA analysis, and three-dimensional photogrammetry, are discussed with particular emphasis on their clinical significance and their complementary role to conventional autopsy. The findings indicate that neck compression accounts for approximately 55% of mechanical asphyxia-related deaths; however, the absence of petechial hemorrhages in 38% of victims complicates the diagnostic process. Proteomic analysis identified 78 differentially expressed proteins specific to mechanical asphyxia. Virtual autopsy demonstrated a diagnostic sensitivity of 90–100% in traumatic deaths, whereas its sensitivity in asphyxial deaths remained below 30%. Based on the obtained findings, the article proposes a unified algorithmic approach for forensic medical experts.

Keywords: mechanical asphyxia, forensic medical examination, suffocation, strangulation, virtual autopsy, proteomics, petechial hemorrhages, histology, diagnostic biomarkers, postmortem imaging.

Introduction

Mechanical asphyxia is an acute pathological condition caused by insufficient oxygen supply to body tissues and excessive accumulation of carbon dioxide. It occupies an important place in forensic medical practice worldwide. According to the World Health Organization (WHO), asphyxial deaths account for a significant proportion of all violent deaths, and their diagnosis remains one of the most challenging medico-legal issues[1].

The main types of mechanical asphyxia include hanging, manual strangulation, ligature strangulation, compressive asphyxia, positional asphyxia, and autoerotic asphyxia. Each type is characterized by specific pathological and anatomical changes and distinctive diagnostic features, making accurate evaluation one of the primary responsibilities of forensic medical experts.

Conventional autopsy methods are often insufficient because many of the macroscopic findings associated with mechanical asphyxia are nonspecific and may be confused with postmortem artifacts. The introduction of modern technologies—particularly postmortem computed tomography (PMCT), postmortem magnetic resonance imaging (PMMRI), proteomics, and microRNA (miRNA) analysis—has significantly improved the accuracy of forensic diagnosis[2].

The aim of this study is to present the modern diagnostic features of forensic medical examination in mechanical asphyxia and to systematize recent diagnostic approaches based on the latest

scientific evidence.

LITERATURE REVIEW

Mechanical asphyxia has long been one of the most extensively studied fields in forensic pathology; however, advances in modern medicine have fundamentally expanded its diagnostic capabilities. A study by Porzionato and Boscolo-Berto (2024) reviewed the current state of forensic diagnosis in mechanical asphyxia and highlighted unresolved issues, emphasizing the importance of meticulous layer-by-layer dissection of the soft tissues of the neck during autopsy.

A proteomic study conducted by Huang et al. investigated protein expression profiles in cardiac tissue using 4D-DIA proteomics. The authors identified 271 and 371 differentially expressed proteins in the strangulation and suffocation groups, respectively, compared with the control group. In addition, 78 proteins were found to be commonly differentially expressed across all forms of mechanical asphyxia, indicating their potential value as diagnostic biomarkers[3].

Scopetti evaluated the diagnostic potential of microRNA (miRNA) in asphyxial deaths. Their findings demonstrated that alterations in miRNA expression associated with hypoxic responses may serve as valuable molecular biomarkers for distinguishing mechanical asphyxia from other causes of death.

A large-scale study by Crudele et al., involving 399 autopsy cases, developed a statistical model based on contingency tables and logistic regression to differentiate hanging from strangulation. The study confirmed the importance of statistical approaches in objectively determining the mechanism of death[4].

A retrospective study conducted in Jordan reported that 72% of hanging victims were male, whereas 82% of ligature strangulation victims were female. Internal neck injuries were absent in 72% of hanging cases, while petechial hemorrhages of the conjunctiva were observed in all cases of manual strangulation.

Regarding virtual autopsy, the comprehensive review by Jangid et al. evaluated postmortem imaging techniques, including PMCT, PMMRI, ultrasonography, and radiography. A retrospective study performed at the Mandya Medical Center (2025) demonstrated an overall diagnostic concordance of 46.7% for PMCT. Its sensitivity reached 90–100% in traumatic deaths but remained below 30% in cases of asphyxia and toxicological deaths[5].

According to a review published in Frontiers in Radiology, the number of scientific publications on PMCT and PMCTA increased steadily between 2019 and 2024. Furthermore, photon-counting computed tomography (PCCT) has been recognized as one of the most promising technologies for the future development of virtual autopsy in forensic medicine.

Methods

This study was conducted through a systematic review of scientific articles published between 2020 and 2025 in the PubMed, MDPI, Frontiers, and ScienceDirect databases. Studies focusing on the forensic diagnosis of mechanical asphyxia, virtual autopsy, postmortem computed tomography (PMCT), and molecular biomarkers were selected for analysis. A total of 28 scientific articles met the inclusion criteria and were analyzed. The findings were synthesized using comparative and analytical methods to provide a comprehensive evaluation of current diagnostic approaches.

Results and Discussion

Recent medical literature indicates that mechanical asphyxia occupies a significant place among violent causes of death. A review of 38 English-language publications published between 2000 and 2025, including autopsy-confirmed cases of asphyxial death, revealed that neck compression accounted for 55% of all mechanical asphyxia-related deaths.

A retrospective study conducted at a medical college in Pakistan analyzed 120 cases of asphyxial deaths. Of these, 61.66% (n = 74) occurred in urban areas, while 38.33% (n = 46) were reported in rural areas. Mechanical asphyxia was identified as the most common type of asphyxial death, with hanging occurring considerably more frequently than drowning and strangulation[6].

A retrospective study conducted in Jordan demonstrated a predominance of males in hanging cases (72%) and females in ligature strangulation cases (82%). Age-group analysis showed that hanging was most frequently observed among individuals aged 21–35 years (51%), whereas manual strangulation was more common in the 36–50-year age group[7].

Table 1.

Main Characteristics of Different Types of Mechanical Asphyxia (Based on Published Literature)

Type of Asphyxia	Predominant Sex	Main Age Group
Hanging	Males (72%)	21–35 years (51%)
Manual strangulation	Females	36–50 years
Ligature strangulation	Females (82%)	2–20 years
Compressive asphyxia	Predominantly males	Middle-aged adults

The conventional diagnostic features of mechanical asphyxia are evaluated at both the macroscopic and microscopic levels. The most important macroscopic findings are as follows:

Petechial hemorrhages (petechiae): Small pinpoint hemorrhages observed in the conjunctivae, sclerae, face, and neck skin are considered one of the classical signs of mechanical asphyxia. However, recent studies have demonstrated that this finding is not consistently present. In cases of neck compression, petechial hemorrhages were absent in 38% of victims. According to a retrospective study conducted in Jordan, conjunctival petechial hemorrhages were observed in 100% of manual strangulation cases but in only 33% of hanging cases[8].

Hyoid bone fracture: Fracture of the hyoid bone is more frequently associated with manual and ligature strangulation than with hanging. The reported incidence of hyoid bone fractures was 69.23% in manual strangulation, 7.81% in ligature strangulation, and only 14.42% in hanging cases. A postmortem radiological imaging study published in 2024 demonstrated that separation of the hyoid bone from the surrounding soft tissues was identified in 44.7% of laryngectomy specimens and 27.2% of autopsy specimens related to other causes of death[9].

Hemorrhages in the neck muscles: Hemorrhagic infiltration of the deep cervical muscles and tissues surrounding the cervical vessels is regarded as one of the most important diagnostic indicators of strangulation. One study described extensive bilateral hemorrhages within the soft tissues of the neck, the vascular bundle, and the perithyroid structures as characteristic injury patterns of strangulation.

Other conventional findings: Cyanosis was reported in 75.54% of cases, vascular congestion in 85.45%, and petechial hemorrhages in 81.81%. Nevertheless, these findings exhibited considerable variability, indicating that no single sign is sufficiently reliable for diagnosing mechanical asphyxia and highlighting the necessity of comprehensive forensic evaluation[10].

Table 2. Diagnostic Value of the Main Autopsy Findings (%)

Diagnostic Finding	Frequency of Occurrence	Source (Year)
Petechial hemorrhages (overall)	81.81%	Retrospective study, 2023
Conjunctival petechiae (manual strangulation)	100%	Jordan University, 2024
Conjunctival petechiae (hanging)	~33%	Jordan University, 2024
Cyanosis	75.54%	Literature data
Congestion	85.45%	Literature data
Hyoid bone fracture (manual strangulation)	69.23%	ResearchGate, 2023
Hyoid bone fracture (hanging)	14.42%	ResearchGate, 2023
Absence of petechiae (neck compression)	38%	ScienceDirect, 2025

Microscopic examination plays an important role in determining the mechanism of death in cases of mechanical asphyxia. Modern immunohistochemical techniques, particularly the evaluation of HIF-1α (Hypoxia-Inducible Factor-1 alpha) and IL-6 (Interleukin-6) as biomarkers of vitality, have become increasingly important in forensic medicine[11].

A study conducted by De Giorgio et al. focused on the immunohistochemical assessment of inflammatory and hypoxic markers in mechanical asphyxia. Their systematic review demonstrated that HIF-1α and IL-6 are valuable biomarkers for distinguishing antemortem injuries from postmortem changes, thereby improving the accuracy of forensic diagnosis[12].

Histological examination of the lungs typically reveals alveolar wall edema, capillary congestion, and emphysematous changes. In cardiac tissue, mitochondrial dysfunction and oxidative stress have been identified. Huang's proteomic study demonstrated significant enrichment of the cAMP and cGMP–PKG signaling pathways, complement and coagulation cascades, TRP channel regulation by inflammatory mediators, and phagosome pathways[13].

Proteomics, the large-scale study of proteins, has opened a new era in the diagnosis of mechanical asphyxia. Huang's 4D-DIA proteomic analysis identified 271 and 371 differentially expressed proteins in the strangulation and suffocation groups, respectively, compared with the control group. Furthermore, 78 proteins were commonly differentially expressed across both forms of mechanical asphyxia, highlighting the considerable diagnostic potential of this technology[14].

In the field of microRNA (miRNA) analysis, the study by Scopetti et al. explored the future prospects of molecular autopsy in asphyxial deaths. Changes in the expression of hypoxia-responsive miRNAs may serve as highly specific biomarkers for mechanical asphyxia. This approach is particularly valuable in cases of "silent" asphyxia, where characteristic macroscopic findings are absent.

Virtual autopsy has become an increasingly important component of modern forensic practice. Postmortem computed tomography (PMCT) and postmortem magnetic resonance imaging (PMMRI) are the principal imaging modalities, each offering distinct advantages and limitations[15].

A retrospective study conducted at the Mandya Medical Center (n = 25) demonstrated that the overall concordance between PMCT and conventional autopsy was 46.7%. The diagnostic

sensitivity of PMCT reached 90–100% in traumatic deaths but remained below 30% in cases of asphyxia and toxicological deaths. These findings indicate that PMCT should be used as a complementary tool rather than a replacement for conventional autopsy.

Jangid's review provided a comprehensive evaluation of postmortem imaging techniques. Postmortem MRI (PMMRI) showed excellent performance in detecting congenital anatomical abnormalities in deceased infants, with a sensitivity of 92.04%, specificity of 97.87%, and an overall diagnostic accuracy of 95.68%[16].

The number of scientific publications on PMCT and PMCTA has increased steadily between 2019 and 2024. A review published in Frontiers in Radiology (2025), based on data from Scopus and Web of Science, demonstrated that research in this field has expanded considerably on a global scale. The latest imaging technology, photon-counting computed tomography (PCCT), offers superior spatial resolution and enhanced material discrimination compared with conventional CT, making it a promising advancement in forensic imaging.

Table 3.
Comparative Analysis of Modern Diagnostic Methods

Method	Main Advantages	Limitations
Conventional autopsy	Gold standard; comprehensive examination	Subjective; destructive
PMCT	Rapid; 90–100% sensitivity (trauma)	<30% sensitivity (asphyxia)
PMMRI	Excellent soft tissue visualization; 92% sensitivity	Expensive; time-consuming
Proteomics (4D-DIA)	Identifies 78 specific proteins	Complex; costly
miRNA analysis	Valuable in “silent” asphyxia	Not yet standardized
3D photogrammetry	Objective injury assessment	Limited clinical implementation

A comprehensive review published in ScienceDirect emphasized the need for a standardized algorithmic approach to the diagnosis of mechanical asphyxia. The authors proposed a five-category classification consisting of mechanical, electrical, toxic (chemical), environmental hypoxia, and pathological (endogenous) asphyxia. This classification recommends detailed reconstruction of the death scene, meticulous layer-by-layer dissection of the deep cervical tissues, and targeted toxicological analysis to clarify uncertain mechanisms of death[17].

When investigating cases of mechanical asphyxia, forensic medical experts should follow several essential steps: (1) examination of the death scene, including body position, clothing, and surrounding objects; (2) external examination for skin injuries, petechiae, and cyanosis; (3) layer-by-layer dissection of the neck structures; (4) examination of the internal organs; (5) histological and immunohistochemical analyses; (6) toxicological screening; and (7) proteomic or microRNA (miRNA) analysis when indicated.

Recent studies, particularly the statistical analysis by Crudele et al. (2024) involving 399 autopsy

cases, demonstrated the high diagnostic accuracy of logistic regression models for differentiating hanging from strangulation. Multivariate statistical analysis enables forensic experts to draw more objective conclusions based on scientific evidence.

The reviewed studies also highlight the significant role of toxicological factors in mechanical asphyxia. Toxicological co-factors, including ethanol, opioids, and sedative drugs, were identified in approximately one-third of all asphyxial deaths. These findings emphasize that toxicological screening should be considered a mandatory component of the forensic investigation in suspected cases of mechanical asphyxia.

Conclusions

Traditional morphological findings alone are not always sufficient for the forensic diagnosis of mechanical asphyxia. Petechial hemorrhages were absent in 38% of neck compression cases, while hyoid bone fractures were observed in 69.23% of manual strangulation cases compared with only 14.42% of hanging cases. Modern proteomic analysis has identified 78 specific diagnostic biomarkers, whereas the sensitivity of postmortem computed tomography (PMCT) reached 90–100% in traumatic deaths but remained below 30% in cases of mechanical asphyxia. Therefore, the most effective diagnostic approach is the integration of conventional forensic examination with molecular biological, immunohistochemical, and toxicological methods. Such a comprehensive strategy significantly improves diagnostic accuracy and contributes to more reliable forensic conclusions and fair medico-legal decision-making.

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